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STAR-VUE INTERACTIVE ASSISTANCE

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TRANSPORTATION DEVELOPMENT CENTRE
POLICY AND COORDINATION GROUP
TRANSPORT CANADA

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Un sommaire en français de ce rapport est inclus avant la table des matières.

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16. Abstract

A knowledge-based system for interpretation of SAR images of sea ice has been developed to the prototype stage. The system contains approximately 100 rules and is capable of classifying SAR images based on a minimal set of feature information supplied by the user. The system runs on a small computer and can be used to assist non-experts make correct SAR ice interpretations. It also contains a SAR image database of representative ice types which can be displayed and used for training.

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16. Résumé

Le rapport décrit un système à base de connaissances pouvant servir d'aide à l'interprétation des images de glaces de mer transmises par un radar à ouverture synthétique (ROS), et développé au stade de prototype. Avec une base d'une centaine de règles, ce système permet de classifier les images ROS à partir d'un minimum de renseignements descriptifs fournis par l'utilisateur. Piloté par un petit ordinateur, il peut servir d'aide à des non spécialistes dans l'interprétation juste des images ROS sur les conditions glacielles. Il renferme également une banque d'images ROS représentatives des divers types de glaces et qui, affichées, peuvent servir comme aide à la formation.

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SUMMARY

Synthetic aperture radar (SAR) has proven to be an ideal sensor for mapping the ever-changing ice conditions in Canada's offshore waters. Both airborne and spaceborne SARs typically achieve ground resolutions of the order of 5 to 30 metres, which is suitable for mapping the important surface characteristics of sea ice under all weather and ambient light conditions.

Recently, in order to provide better, more reliable ice information to the Canadian Coast Guard, the Atmospheric Environment Service (AES) commissioned a new SAR ice reconnaissance system. Data are collected and processed in real time on board a SAR-equipped Challenger jet aircraft and are downlinked directly to Coast Guard icebreakers. Data received are displayed in the form of imagery on board ships using a computer display system called STAR-VUE, which is now standard equipment on all major Coast Guard icebreakers.

Because of this system and with Radarsat coming in the next few years, Coast Guard will see a dramatic increase in the amount of SAR data that is received and used by their icebreaking fleet. There is an obvious need to train Coast Guard Officers in the practical use of this new data source for the task of piloting ships safely through ice.

It is possible to determine ice type, hence infer ice thickness using both SAR and a knowledge of the processes that act on an ice sheet during its growth and development. One of the main problems with this procedure however, is the fact that an expert is usually required to make these interpretations. This report outlines the development of a knowledge based computer assisted training system to assist Coast Guard personnel with the interpretation of SAR images of sea ice.

An Expert System approach has been taken for this development for a number of reasons:

1. Ice Interpretation Experts who are familiar with SAR are few in number and not always available. They can also be very costly, particularly if required for every Coast Guard icebreaker and ice office.

2. Experts, unless proficient and explicit teachers usually do not have a structure to explain their knowledge and may have difficulty communicating with others. Moreover, experts often use different terminologies for the same domain concepts.

3. Consistent training, based on well structured knowledge, can be provided by employing knowledge based computer systems. This has not been possible to date since the specific classification of ice types and the features that contribute to the definition of these types, is a subject of some controversy and has not been well documented. It is further complicated by the fact that experts often disagree about the importance of features required for classification.

4. The performance of non-experts can be significantly enhanced by the provision of proper training in SAR interpretation. Computer assisted training has been shown to be very effective. These programs allow students to proceed at their own pace and, if correctly structured, allow them to learn about those areas where they need help.

5. Once assembled, the knowledge for this project can be used for many applications, including development of training systems, briefing systems and on-line assistants.

6. Computer hardware is becoming very inexpensive so that low cost systems can be provided for a large number of locations even on board ships for on-going training and assistance.

Knowledge Based System

A knowledge-based system has been developed to the prototype stage. It demonstrates that an expert system approach can be applied to this and other complex image interpretation problems. Developing the system has also resulted in a much better understanding and structuring of the underlying knowledge required for the job of ice classification.

The system is capable of classifying SAR images based on data input from users. It runs on a small computer and can be used in a stand alone mode, e.g. on the bridge of a ship, to assist non-experts make ice interpretations. It also contains a digital SAR image data base of representative ice types which can be displayed and therefore used as a training system by observing the way the system classifies.

SOMMAIRE

Le radar à ouverture synthétique (ROS) s'est révélé le capteur idéal pour donner une vue "instantanée" des conditions glacielles dans les eaux littorales du Canada. Qu'il soit aéroporté ou satellitaire, ce radar donne généralement une résolution au sol de l'ordre de 5 à 30 mètres, suffisant pour détecter les caractéristiques de surface significatives des glaces de mer dans toutes sortes de conditions atmosphériques et d'éclairage.

Afin de fournir à la Garde Côtière canadienne (GCC) une information glacielle plus fiable et de meilleure qualité, le Service de l'environnement atmosphérique a récemment mis en service un nouveau système de reconnaissance des glaces par ROS. Un avion à réaction Challenger équipé d'un radar ROS survole la région à reconnaître et l'information obtenue est aussitôt traitée et transmise à destination des brise-glace de la GCC. Cette information est affichée sous forme d'imagerie grâce au système de visualisation Star-Vue, devenu équipement standard à bord des principaux brise-glace de la GCC.

La mise en service du Star-Vue et aussi, dans quelques années, du satellite Radarsat fera que les brise-glace de la GCC auront à leur disposition une quantité énorme d'informations radar. D'où la nécessité d'avoir à leur bord des personnes qualifiées capables d'interpréter ces données et de les utiliser pour le pilotage sûr des navires dans les glaces.

Il est possible de déterminer le type de glace et d'en déduire l'épaisseur grâce au procédé ROS appuyé sur une connaissance des processus de formation et de croissance d'une banquise. Mais, pour cela, il faut quelqu'un en mesure de faire les interprétations nécessaires. C'est de là qu'est né le besoin d'un système de formation assisté par ordinateur à base de connaissances, dont l'étude est décrite dans le présent rapport.

Il a été décidé de faire appel à un système expert à base de connaissances pour les raisons suivantes:

1. Les spécialistes de l'interprétation des conditions glacielles sont peu nombreux et pas toujours disponibles. En augmenter le nombre peut être coûteux, surtout s'il en faut un à bord de tous les brise-glace de la GCC et dans chaque bureau de reconnaissance des glaces.

2. À moins d'être doublés d'un pédagogue talentueux, ces spécialistes éprouvent de la difficulté à communiquer leur science qui n'est généralement pas bien structurée. Qui plus est, ils ne se servent pas tous de la même terminologie pour décrire les mêmes phénomènes.

3. Un système bien structuré à base de connaissances, piloté par ordinateur, constituerait l'outil de formation souhaité. Une telle solution ne pouvait pas être envisagée jusqu'ici à cause du désaccord qui régnait à propos de la catégorisation et de la caractérisation des divers types de glaces et du fait qu'il n'existait aucune typologie formalisée. À ceci s'ajoutaient les divergences d'opinion des spécialistes quant à l'importance qu'il fallait accorder à telle ou telle caractéristique aux fins de la classification.

4. Une bonne formation en interprétation des données du ROS constituerait un atout précieux, notamment par le procédé efficace de l'enseignement assisté par ordinateur. Il permet à chacun d'avancer à son rythme et d'approfondir le ou les secteurs qui lui sont les moins familiers.

5. Une fois structurée, la base de connaissances pourra servir maintes applications telles que la réalisation de systèmes de formation, d'information ou d'aide au pilotage.

6. Le matériel informatique devenant de moins en moins coûteux, il devient possible de multiplier les centres de formation continue ou d'aide à la décision - on peut même envisager d'en équipper les navires.

Systèmes à base de connaissances

Le système à base de connaissances étudié et développé au stade de prototype a montré son aptitude à servir comme aide à l'interprétation d'imagerie radar sur les glaces et d'autres imageries plus complexes. Cette recherche a permis de déblayer les connaissances en matière de classification des glaces et de les structurer.

Le système expert permet de classifier les images du ROS à partir de paramètres fournis par les utilisateurs. Piloté par un petit ordinateur, il peut fonctionner en mode autonome, sur une passerelle de navigation, par exemple, pour aider des non spécialistes à interpréter l'information sur les glaces. Il renferme également une banque d'imageries ROS numérisées représentatives de divers types de glaces et qui, affichées, permettent à un observateur en formation de suivre le raisonnement qui permet au système de classifier les glaces.

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1. INTRODUCTION

1.1 Background

Typically, computers are designed to process a wealth of numeric information. If a problem can be reduced to numbers, it can usually be solved by a computer.

Computers can also be used to process information symbolically, in which case the atom of information is not a number but a symbol for which there are usually no numerical operations defined. By representing information in various structures of symbols (lists) it is possible to define and solve an entirely new class of problem with computers.

For the last 30 years researchers have been working in the field of Artificial Intelligence (AI), a subfield of Computer Science that typically involves symbolic problem solving to approximate human behavior with a computer. Within the field of A.I. special attention has been focused on such areas as Robotics, Speech Understanding, Image Understanding, Planning Systems and Knowledge Based or Expert Systems. In the last few years Expert Systems gone beyond laboratory testing and have had a significant impact on the commercial world.

In simplest terms, the notion behind an Expert System is to capture the problem-solving expertise of a human being and represent this knowledge in a computer in such a way that the computer can approximate the expert's ability to solve a particular class of problem. It is estimated that there are currently over 2000 Expert Systems in use in North America today. Examples of systems include those used for: medical diagnosis, faultfinding or troubleshooting of complex electronic systems, equipment configuration, scheduling, etc.

Both airborne and spaceborne synthetic aperture radar (SAR) will have an increasingly important role to play in future ice reconnaissance programs. SAR has been shown to be an ideal tool for the classification of sea ice since it is not hampered by darkness or atmospheric conditions and different ice types can be determined from characteristic signature patterns.

One of the main problems with using SAR for ice classification, however, is the fact that under most circumstances an expert is required to interpret the radar imagery . This can be a time-consuming process for those individuals who must analyze vast amounts of radar data and limits the utility of SAR for those marine vessels and offshore operators who require ice information in real time and who do not carry a resident ice expert.

In response to this need, TDC sponsored INTERA to undertake the development of a Knowledge Based System to assist Coast Guard Officers and other non-experts with the interpretation of SAR images of sea ice.

Requirement For Ice Information

Sea ice has always posed a significant hazard to shipping and other marine activities. One of the major difficulties has been the lack of detailed information available to mariners concerning ice conditions beyond visual or ship's radar range. Ships navigating in ice have had to make guesses about course selection based on their previous operational experience in an area or perhaps by using limited reconnaissance from helicopter and/or the limited information distributed in the form of ice maps, charts, reports, etc.

The information required by ships operating in ice includes:

- identification of features such as individual pressure ridges; rubble

fields, leads and polynas;
- ice extent;
- identification of ice type and age (i.e., multi-year, first-year, icebergs);
- ice thickness; and
- internal stress (areas of convergence or divergence).

The newly available AES synthetic aperture radar system will increase the level of ice information available to ships and thus extend a ship's range of operations in ice based on reliable first-hand information. SAR has been used in support of commercial operations in ice or iceberg infested waters since the early 1980's. A primary advantage of SAR and, for that matter, real aperture systems (SLAR) is that the return signal from multi-year ice, first-year ice, pressure ridges and glacier ice all have somewhat distinct signatures.

SAR vs SLAR

A real aperture SLAR system can be thought of as a marine radar system pointed downwards from an aircraft instead of a ship. As the aircraft flies in a straight line, two swaths are imaged, one to either side of the aircraft, with a dead zone underneath the aircraft of width about twice the aircraft altitude.

As in a conventional radar, the resolution capability of a SLAR is a function of range from the aircraft. This depends on the particular radar, but typical values are about 40 m in the near edge of a swath to about 200 m - 400 m in the far edge of a 50 km swath. The signal return is also a function of the angle of incidence of the radar signal. At low angles of incidence, the percentage of back-scattered energy begins to fall off, causing the "texture" of the return signal to vary across a swath width. These problems with resolution and texture hamper the interpretation of standard SLAR imagery for ice conditions.

A SAR can be thought of as a dramatically upgraded SLAR. The resolution of a SAR is improved by post-processing the return signal. A doppler history is recorded for a target as the aircraft passes by, and through the use of a technique called doppler compression, a point image is created from that doppler history. The result of this and other processing is that the resolution of a SAR is independent of range.

AES SAR

The Atmospheric Environment Services now operate a new, dual side looking, X-band, digital, real time, multi-look SAR carried aboard a Challenger jet aircraft. In its wide swath mode (100 km per side) it is capable of imaging more than 600,000 sq.km per mission from altitudes typically above 11 km. Because the systems are fully digital, and because they are SARs, the radiometric properties of the images generated are much more uniform than with a SLAR. The result is that not only is resolution constant across a swath, but the characteristics of the image across the track width are also nearly constant. This latter characteristic makes it much easier to use a SAR for ice interpretation than a conventional SLAR.

Data are displayed, processed, stored and downlinked through a specialized Data Management Unit aboard the aircraft. The downlinked data are received aboard Coast Guard icebreakers where the imagery is processed and displayed by a computer system called STAR-VUE. STAR-VUE was designed and built by INTERA with assistance from TDC and Canarctic Shipping as a shipborne tool to enhance the utility of the SAR imagery being presented in real time.

Ice Interpretation With SAR

It is possible to determine ice type, hence infer ice thickness using both SAR and a knowledge of the processes that act on an ice sheet during it's growth and development. Normally, in first-year ice, a saline layer migrates into the snow cover and acts as an inefficient reflector. This causes first-year ice to appear relatively smooth to the radar, resulting in a rather low return (dark tone). Older ice has gone through at least one melt season. It is less saline and the brine drainage has left behind small imperfections with only a small amount of salt. Any snow is relatively dry and fresh. The imperfections are of the scale of the radar wave (cms) and act as small isotropic radar scatterers. Isotropic scatters mean more energy is back-scattered, relative to smooth first-year ice, and older ice appears brighter than first-year ice. When first-year ice freezes at temperatures below 20°C, salt is extruded from crystals and forms a saline layer on the surface. This combines with the "frost flowers" which form at these temperatures to make very efficient scattering centers, whose size is of the same order as the radar wavelength. These act as isotropic scatterers and the surface appears very bright. This ice is identified as first-year ice by comparison with previous imagery, by texture and by the shape of the features. Normally, it is possible to identify this ice as first-year by the fact that it occurs in leads or polynas.

1.2 Knowledge based interpretation system

There is an obvious need to train Coast Guard Officers and other non-experts in the practical use of SAR for the task of piloting ships safely through ice. For this TDC sponsored project a Knowledge Based Assistant and Training System was developed to the prototype stage. The decision was made to develop a system that would see the application of two major technologies to this problem: 1. Expert Systems and 2. Computer Assisted Learning.

The development of this system was not without technical risks. The task of ice classification using SAR is a very complex. The human visual system is extremely efficient and it is difficult for experts to describe what it is they do when they classify. It is also difficult for different experts to agree on the important features needed for classification. This makes it difficult for them to teach the subject to novice users.

Although the job of teaching seems simple, it is a non-trivial job to structure the knowledge base for a training application. The system must find out what level of understanding the student has (student modelling) and guide his progress through the system so that he learns the important concepts. Note that no commercial Expert System shells exist for education even though Intelligent Computer Aided Instruction (ICAI) is a rapidly growing field and hundreds of research papers are written each year on the subject.

The hardware required for such a system also had to be leading edge. In order to keep costs down it was decided that the delivery system would be the same as the development system and run on a small workstation or personal computer. The system also had to be capable of running intermediate level Expert Systems Tools and be capable of rapidly displaying high resolution SAR images (1024x1024) in quick succession.

At the start of this program INTERA assembled a project team in order to build the Expert Training System. This team consisted of:

- INTERA personnel to provided management and domain experts for the ice classification problem;
- the Advanced Technologies Department of the Alberta Research Council to provide assistance with the knowledge acquisition, knowledge representation;

and computer assisted instruction; and
- Dr. Jerry Ells of the Psychology Department of the University of Calgary to assist with knowledge acquisition and verification.

Project Plan

The original project plan for this contract was divided into 2 phases: Phase 1 called for the building up of a matrix of SAR images of different ice types. These images were then to be used by the project team to capture information from the experts on how they do the job of ice classification. Phase 2 of the project called for the development of a prototype system. Phase 1 of the project is referred to as the Knowledge Acquisition Phase since this was it's major focus. Phase 2 is referred to as the Prototype System Development.

The structure of the Expert System was arranged into three sections:

1. The Knowledge Base, containing the expert's factual and relationship knowledge represented in one or more different ways;
2. A Knowledge independent inference engine, containing the computer instructions to reason with the information contained in the Knowledge Base;
3. A user interface connecting the user to the inference engine.

2. KNOWLEDGE ACQUISITION

It was clear from the start of this program that the specific classification of ice types and the features that contribute to the definition of these types is a subject of some controversy and is not well documented. INTERA's initial interviewing and questioning of several ice classification experts revealed that it was very difficult for them to describe what they do when they classify. Experts generally have no model upon which to base their expertise.

Following preliminary research which involved two INTERA employees who discussed the process of ice classification based upon their perception of 25 Synthetic Aperture Radar (SAR) images, a method was designed to elicit from knowledgeable subjects information pertinent to ice analysis. This methodology involved subjects making comparisons between three images viewed in sequence in order to describe similarities and differences among them.

A series of structured experiments were therefore undertaken to elicit this knowledge using an image display system (STAR-VUE) and a computer based knowledge engineering tool developed by Shaw and Gains [1] which is based on Kelly's Personal Construct Psychology [2].

Repertory Grids

The knowledge engineering called KSSO is an interactive computer aid which incorporates techniques for eliciting the expert's vocabulary and structuring some aspects of the domain knowledge. The program uses interactive elicitation of repertory grids to elicit knowledge from experts and can perform entailment analysis of the grids to derive inference rules with which to prime expert system shells. The expert interacts with a program that encourages him to make clear the distinctions he uses in applying his expertise. This helps him to structure his knowledge and identify and formalize his concepts.

A repertory grid is a two-way classification of data in which events are interlaced with abstractions in such a way as to express part of a person's system of cross reference between his personal observations of the world (elements) and his personal constructs or classifications of that experience. The constructs are the terms in which the elements are similar to or different from each other. Each construct therefore has two poles each of which has meaning with respect to its opposite.

The most common method used for eliciting a construct is the minimal context form or triad method. The elements are presented in groups of three-this being the least number that will produce both a similarity and a difference. The subject is asked to say in what way the two are alike and thereby different from the third. The mapping of the elements onto the constructs produces a two dimensional grid of relationships which can be represented as a numeric data structure.

The methodology employed for this project involved six experts, making comparisons between a triad of randomly chosen SAR images (elements), viewed in sequence, in order to describe similarities and differences. Subjects completed 20 trials and were asked to indicate: how a given image was different from the other two images observed, how the other two images were similar, and to generate a construct name for the features etc. that distinguished these images. Subjects then rated each image with respect to this construct using a five point scale to indicate the presence or absence of a particular feature. Subjects were also asked to rate the importance of each construct to the task of ice classification. Examples of constructs include the presence or absence of such features as: angular floes, fine texture, homogeneous tone, ridging, etc.

A repertory grid was constructed as a way of representing these constructs which contained a set of bipolar distinctions made about the images. The KSSO program contained several features to analyze and determine inter-relations between constructs using distance-based cluster-analytic techniques, principal components methods, and Shaw's FOCUS. Constructs from all experts were pooled into an initial set of 31 constructs.

Construct Matrix

The second stage in the knowledge acquisition phase involved the establishment of a construct matrix where the subjects were asked whether a particular pooled construct was present or absent on a given set of images and to indicate the importance of the constructs to each ice type. The images included examples of the following ice types: New Ice, First-Year Ice, Second-Year Ice, and Multi-Year Ice. The results of this session showed that experts strongly agreed on the ice type when certain key constructs are either unequivocally present or absent. More complete experimental details of the above procedures can be found in Appendix A. The 31 constructs generated are described in appendix B.

For any given construct we may regard the number in the grid as a vector of values giving the assignment of each element in turn to one or other of the poles of the construct. Two constructs which are zero distance apart are such that all elements are construed in the same way and hence we might infer that they are being used in the same way. The FOCUS algorithm is a distance-based hierarchical cluster analysis technique that sorts the constructs into a linear order such that constructs closest together in the space are also closest in the order. Thus the grid is presented by the neighboring of the constructs and elements. Appendix C contains repertory grids from several experts displayed with the FOCUS analysis. From the analysis we can see that groups of features describing different ice types are clustered together. These are the features which these experts use to classify a particular ice type. They start to form the basis for rules that can be used for classification. These same data are also represented using another distance-based algorithm (PRINGRID) using standard principal components. This technique shows the major dimensions along which the experts are making decisions.

Appendix C also contains the results of an algorithm called SOCIOGRID which compares the repertory grids elicited from the group. By comparing pairs of these grids it was possible to map the extent of overlap of the agreement and understanding between experts. From this analysis it was clear that experts share only parts of their terminologies and conceptual systems. SOCIOGRID was used to focus discussion between experts on those differences between them which required resolution. More information on repertory grid analysis can be found in the papers listed in the references.

The above experiments generated a knowledge base of features and constructs which are used by Experts for the job of ice classification. It was obvious that this knowledge base could be organized into a hierarchical structure starting with basic elements such as tone and texture and proceeding up the scale to features, patterns, processes and classifications. The beginnings of a glossary of basic features and processes which can be used for classification is included in Appendix D for reference. Note that this is the first time that this kind of knowledge has ever been available for ice classification.

Regardless of the success of the Expert System INTERA feels that the development of this knowledge base is an important advance and will change the way conventional training is conducted in the future. Preliminary trials at a course offered by York University (1989) have shown that novice users can quickly arrive at proper classifications by using a structured methodology and identifying appropriate features.

Other Knowledge

It was clear however, that experts use a great deal more information when classifying, than their knowledge of image features. Location, time of year, proximity to land, winds and currents must also be considered along with the history and recent study of an area. It was necessary then to augment the preliminary knowledge base with additional knowledge. Two key experts were used for this task along with additional example images and an ongoing interviewing technique.

It should be noted that the image data sets used in these experiments were limited to the ice conditions of the American and Canadian Beaufort Seas and the Canadian Arctic during freezing and melting conditions. Thus the domain of knowledge contained in the final system is restricted to these areas.

Although this knowledge base developed was by no means complete, (since it is very difficult to identify all conditions), it was complete enough to proceed with Phase 2 of the program i.e. the building of the prototype system. This process allowed the project team to gather more information from the Experts and refine and verify the knowledge base. It should be pointed out that Knowledge Acquisition is really an ongoing task. Expert System development requires the evaluation of a series of successively refined prototypes before a final system is produced.

3. KNOWLEDGE REPRESENTATION

The major areas involved in the system design process concerned the various forms of knowledge representations to be used, the inferencing mechanisms to be applied to those representations, and the assignment of various kinds of knowledge to those representations. Thus the design needed to specify:

1. The knowledge structure i.e. a description of, the identity of, and organization of, the knowledge including:
   - -knowledge items to be included in the knowledge base
   - -organization of the knowledge
   - -representation of each knowledge item
2. Inference mechanism
3. Control Mechanism
4. Data Interfaces i.e. the manner and connections by which data and information will be passed in and out of the application to the
   - -users and,
   - -data bases

In addition the complete development and delivery environment was also specified.

INTERA also proceeded to build up a matrix of SAR images of the different ice conditions for this application. The current image data base used for the prototype development consisted of INTERA's digitally archived STAR-1 and STAR-2 data acquired for commercial clients and for Coast Guard and Atmospheric Service during 1986 through 1989 campaigns (see Appendix E). These data are divided into regions which approximately represent similar ice conditions on a macro scale. It is clear there is limited SAR coverage (restricted to one or two missions) for most areas. It is also almost exclusively data of winter ice.

Since one of the goals of this program was to examine how the techniques of Artificial Intelligence could be applied to ice interpretation, the decision was made to make the prototype system a true Expert System. It would classify like an expert rather than simply being a computer training system. A rule based system was chosen for the prototype since the classification procedure naturally seemed to fit into this form of representation.

Rules

The rule sets were written for specific ice types and rely on the presence of image features and elements, as well as other information, such as time of year and geographic location. Only affirmative constructs are used for the "ice-type rules". These "affirmative" rules require that the appropriate constructs or features be present in the image. An example of an affirmative rule is:

If there is evidence of floe
And floe.composition is "Conglomerate"

And floe.shape is "Round ","Round-Angular"
And tone.inner is " Grey", "Bright Grey", "Bright"
Then Old_Ice_3 is confirmed

In addition to affirmative rules a second type of rule termed "supportive" is also used. These supportive rules evolved out of the process of determining unique characteristics for each ice type, a task which proved to be rather difficult. There are however, several characteristics for each ice type which typically lend support to the interpretation, but which are not unique to that ice type. These are termed supportive constructs since they lend support to the conclusion reached via the affirmative rules. Once the affirmative rules are fired and a conclusion reached, the system checks the supportive rules to verify that this conclusion is correct. These supportive rules are also particularly valuable in training situations when expressed along with the affirmative rules since they show the user how the system arrived at it's classification. An example of a supportive rule is:

If there is evidence of floe
And there is evidence of floe.size
And there is evidence of ridge
Then Old_Ice_3 _support is confirmed

One more rule type has also been incorporated into the system. This rule type, termed "precluder" is used to exclude ice types whenever possible. The reasoning here is that there are times when an ice sheet has so few features that a classification is almost impossible. It is however, usually possible to exclude some ice types, which is in itself, useful for the classification process. An example of an precluder rule is:

If there is evidence of rafting
Then not_first_year is confirmed

The above rules have not been designed to handle mixtures of different ice types since this was seen as a future development. It is interesting to note that the prototype runs in an exhaustive manner searching the knowledge base for matches until all rules have been checked. If the area of interest actually contains more than one ice type, the system will output results indicating that different ice types are present.

One addition to the system has been the division of the Canadian Arctic into four unique ice zones. These zones were determined from the identification of unique ice characteristics identified on numerous images. An example of one of these zones is the Northern Arctic Islands. Within the zone are three landfast multi-year ice plugs. By having the user identify the geographic area the system is more quickly able to determine the ice type.

4. SYSTEM REQUIREMENTS

A requirements document for the Knowledge Based Ice Interpretation System was developed early on in the program. It was not intended to be a narrow set of requirements but a rather broad and flexible document outlining the objectives, goals and desired capabilities of the proposed system. The requirements of this system are briefly described as follows:

The prototype ice classification system was to be developed using a commercial expert system shell (Nexpert Object) and consist of a graphical user interface, inference engine, and SAR image database.

The user was to interact with the system via a menu driven graphics interface. Users would be asked to view a SAR image and then asked to input easily recognizable features, patterns, constructs, and other relevant information needed by the system for ice classification. The assumption is made that the user understands the terminology used by ice classification experts to describe features, patterns etc.

The system would be designed to classify only SAR image that contain one predominate ice type. A representative sample of SAR ice images was to be contained on the system so that it could be used for training by example i.e. by witnessing the way the system arrives at a classification. Images must be represented at two different scales: an overview image (100 m pixel resolution) will be displayed along with a high resolution (15m pixel resolution).

The prototype system must be capable of displaying both a full resolution and overview SAR image of the same area. It must be able to store a minimum of 10 pairs of images representing at least 5 different ice types at selected times of the year. Each image pair may be used to show more than one ice type. The area of interest is to be outlined with a colour box.

The ice types must include open water, new ice, first year ice, second year ice, and old ice. The user is asked to pick out features shown in the image and provide other information which may be required to classify the ice via a series of menus.

The system will classify selected areas shown in the images with respect to ice type based on user input.

Operational Requirements

The system must be capable of performing two tasks:

(1) It must be capable of showing examples of different ice types using images stored on the system.
(2) It must be capable of classifying ice based on information supplied by the user via a series of menu prompts.

Note the system was not required to be a complete training system. I t is clear however that a more complete training system could be constructed once this prototype system was completed.

Design Constraints

The hardware chosen for this system consists of a Macintosh IIx computer with 4 Mbyte RAM and 140 Mbyte hard disk. The display is a Radius high resolution colour monitor with 1100 x 800 pixel resolution.

Attributes

The prototype system will be written for the Macintosh but software portability to other systems is a desirable goal.

The development cycle for phase 2 of the program involved:

1. Generation of the systems requirements document.
2. Completing the overall system design.
3. Developing and testing a series of successively refined prototypes.
   Note: this involved extensive testing by both the Experts and the users of the system.

4. Development of a final delivery system.

5. PROTOTYPE SYSTEM

Expert System Shell

Neuron Data Inc's. expert system shell, Nexpert Object was chosen for the prototype after careful evaluation of A.I. products on the market. By A.I. standards, Nexpert offers the kind of power and flexibility in Expert System development tools found in much more expensive products like Teknowledge's S.1 or Inference's ART at a fraction of the cost. Basically Nexpert provides a framework in which to build a knowledge base - a set of rules that contain an experts knowledge. Knowledge bases can have up to 500 rules and can be edited, modified, or browsed in the form of a collection of flowcharts and block diagrams. To solve problems Nexpert searches through the knowledge base by means of a special inference engine which processes the data and hypotheses entered by a user and yields a set of conclusions.

Nexpert is a relatively low cost tool written in "C" which can run on a variety of PC's, workstations, and mainframe computers. Thus, applications developed on one computer system can be easily ported to other systems. Nexpert Object is a hybrid tool, combining structured representations and rules. It is built around a reasoning kernel with forward and backward chaining, automatic goal generation, multiple inheritance, and direct calls to external routines.

Nexpert has excellent tools for developing a knowledge base. The rule editor provides a template for creating rules and specifying the arguments, actions and conclusions to be included in the system. Rules can trigger actions that affect the values of data in the system. Rules also define operations such as calculations and can trigger other rules and rules that link rules.

The heart of an Expert System is the inference engine which processes the knowledge base to solve problems. Nexpert's inference engine approaches problems in three ways: Forward chaining is a process whereby Nexpert seeks out hypotheses that match the evidence (data) and investigates them. Backward chaining is the opposite - Nexpert works from suggested hypotheses to find the evidence. The third method is a mixed approach in which Nexpert gives priority to suggested hypotheses and later focuses on any new hypotheses generated from evidence given during initial explorations. This latter approach was utilised for the ice classification problem.

A higher level function within Nexpert was also utilised for the classifier-the Category Editor. The Category Editor allows one to classify data (conditions or IF statements in the Rule Editor) by categories. The Category Editor allows the system to act more like a human (in our case an ice interpretation expert) by assigning priorities to each category so the system investigates data in a meaningful order.

Nexpert also has an excellent developer's interface. Nexpert's Browse Network was heavily utlised for this program. This option shows one the system's reasoning path toward a given solution by drawing lines between related conclusions. This feature enabled the experts to see the sequence of choices leading to a particular conclusion and to determine the role of any rule or set of rules in the final decision. The overview option also allowed the entire rule network to be viewed. This was an invaluable tool for the development of the prototype since it allowed both the system's developers and the experts to see a graphical representation of the rules and to trace the reasoning of the system during processing. Figure 1 shows a portion of the final Rule Network that was built up for the prototype system. Note the red boxes and branches indicate rules that were fired during a session.

Nexpert reporting function was also useful for generating printouts of rules and conclusions. More technical information on Nexpert can be found in Appendix F.

Hardware

The system was developed on a 68030 workstation (MacIIx) containing 4 Mbytes of RAM, a 160 Mbyte internal hard disk and a high resolution (1152x882) colour monitor. The Mac was chosen because it is a relatively low cost computer with excellent graphics and development tools. Figure 2 shows the final configuration chosen.

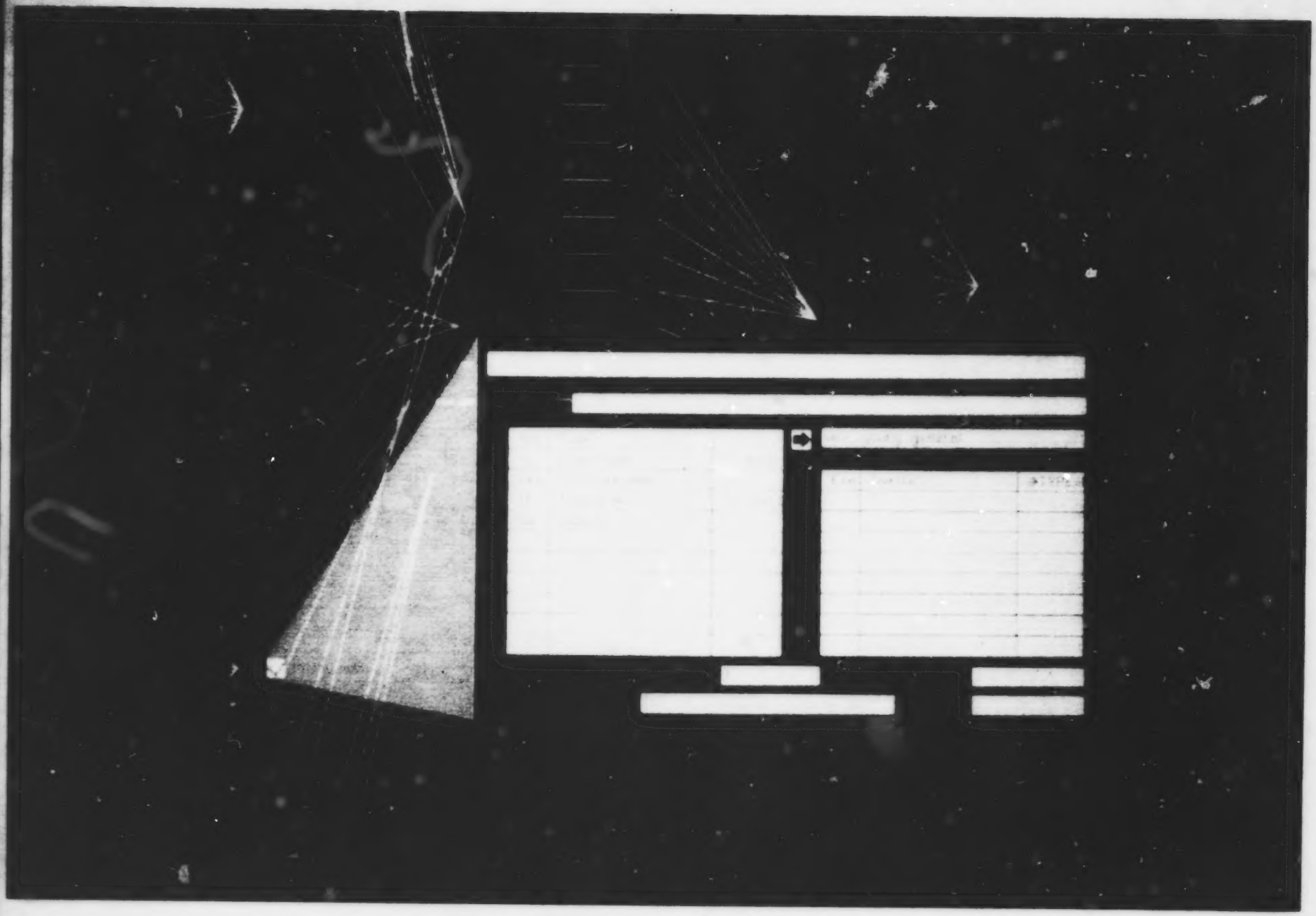

Figure 1. NEXPERT Rule Network and Rule Editor

Figure 2. Prototype System Configuration

Prototype System

The prototype system processes rules on the basis of hypotheses suggested and from user input. The system proceeds with a depth first search from a root context to a context selected. A series of parameters, stored in meta-slots, have been customized to generate menus for user input whenever input is required during the inferencing process.

A custom graphics user interface was written for this application. This interface allows both text and imagery to be combined on the display. Digital images that are stored on the system are displayed in two windows like STAR-VUE. One window displays an overview image of wide areal extent. This overview image was found to be important since it contains the contextual information necessary for classification. A second window displays a zoomed-in portion of the overview image at full resolution. A coloured box is used to outline the area of interest and focus the user's attention on a given ice type. A third window located at the bottom of the screen is used for user interaction. The style of this interaction is based on the Macintosh interface standard where the user interacts with the system via a mouse and in some instances with an attached keyboard. A series of tri-state buttons are used to represent menu choices.

An important feature of the user interface is the use of templates. These templates are used to solicit information on criteria such as tone and texture where it is difficult to express in words a relative value for these attributes. For example, the user is presented with a grey scale and asked to match the overall tone of the image. Similarly a series of examples of various textured images are also presented and the user asked to match the image to one of the examples.

An extensive help facility is also incorporated into the system. The meaning of various terms used by the system is displayed automatically any time the user moves his cursor over a referenced term. In addition, actual image examples of various features and terms can also be displayed by hitting the help button.

In should be noted that the prototype development went through several iterations and evaluations before the current system emerged. This process of prototyping and evaluation proved to be an excellent way of soliciting further information from the experts and made it easier for them to communicate with the system programmers.

6. SYSTEM OPERATION

The prototype system has been designed to analyze any SAR image in the geographic regions outlined earlier. The prototype system contains a number of SAR images, stored in digital format on disk that may be brought to the screen for analysis. Because of disk space limitations with the prototype the number of images stored on the system is restricted to 10 scenes. This is not a limitation on the system however, since more imagery could easily be stored on a larger disk or stored on other media like magnetic tape, optical disk, etc.

The system can also be used to analyze other imagery which may be in the form of positive prints, film negatives, etc. Thus the reasoning kernel operates independently of the imagery stored on the system - it is truly an Expert System. The reasoning kernel for that matter may be ported to other systems if desired to be used as an on-line assistant or in other training situations.

The prototype was built on a small computer to show how useful this system could be for training. Users are asked to view an image and are then asked to input easily recognizable features, patterns, constructs, and other relevant information which is used by the system for classification. The area to be classified on the stored images is outlined and represents a single ice type. The system classifies the ice into one of the following types: New, Young, First-Year, Second-Year, and Multi-Year. First-Year ice is further divided into smooth, ridged, rough, and very rough.

Figure 3 shows the first screen presented to the user on the prototype. The user is asked for information on the geographic area and time of year for each SAR image to be classified. This is the first level of information required by the system. On the prototype this information is entered via a series of pull-down menus. Geographic Location includes four ice zones (in this example Arctic Ocean Nares Strait). For the purpose of SAR image analysis season is melt or no-melt (in this example no-melt). Note that a full training system would have this information contained in its data base along with the imagery. The user's attention is focused on the area within the green box on the display.

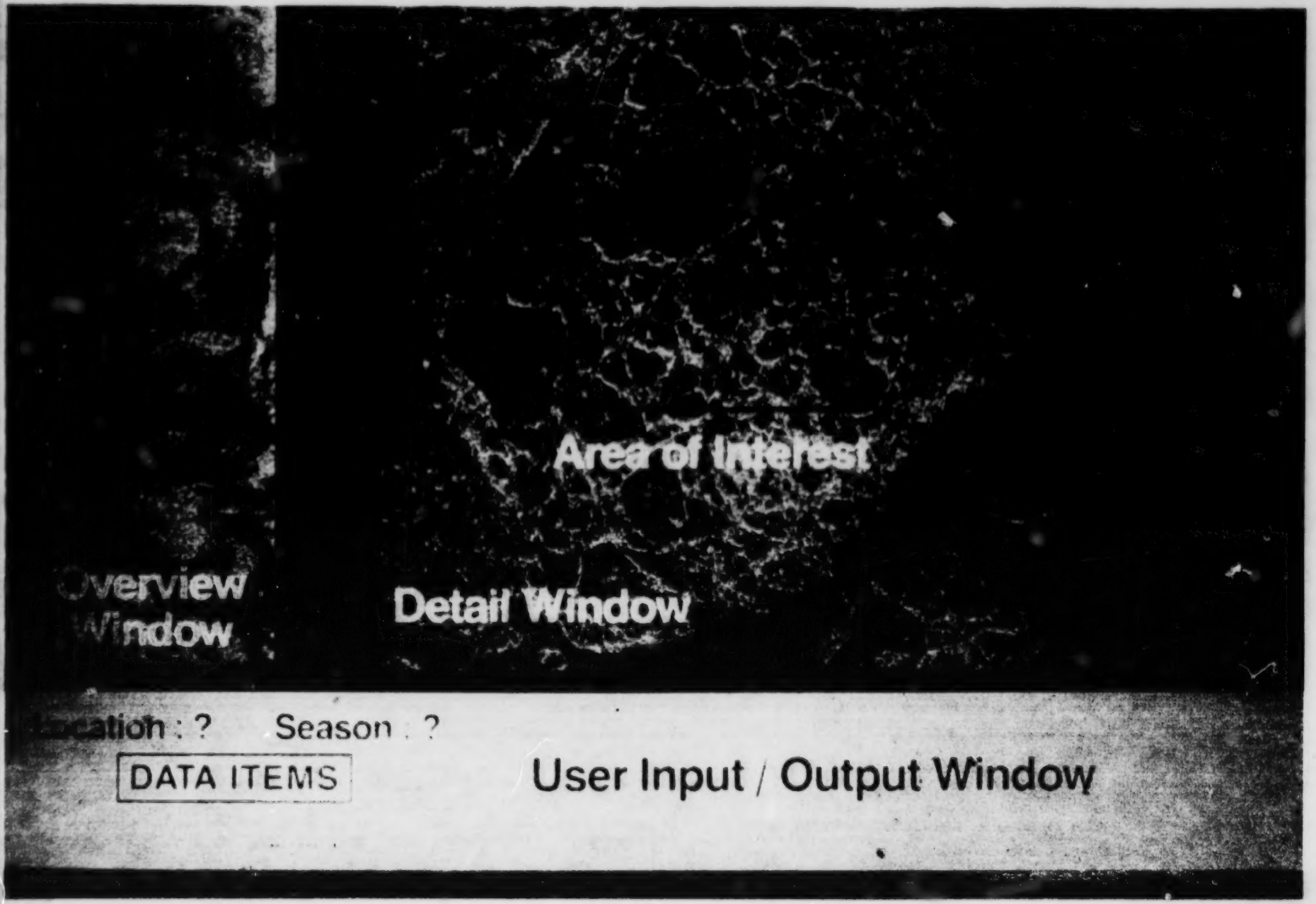

Figure 3. First Input Screen

Figure 4 shows the next screen shown to the user. On this screen the user is asked to input information on floes, tone and texture. Under the floes category the user is asked to input information on floe composition, shape, floe size and floe perimeter. An important feature of the system is that if the user does not understand the terminology by clicking on the help button the system displays examples of each of these terms. For the ice type shown in Figure 4 the floe composition is conglomerate, floe shape rounded, perimeter shows rubbling, and floe size is greater than 2 km. The user enters information into the system via a series of tri-state buttons shown on the bottom left of the display.

Tone and texture information is entered into the system by pointing to one of the valuator boxes that most closely resembles the ice image to be analyzed. These valuators were incorporated into the system since it is very difficult for people to describe what they mean by terms such as tone and texture. For example dark grey, grey, bright grey, very bright grey are very subjective and often lead to confusion between different users.

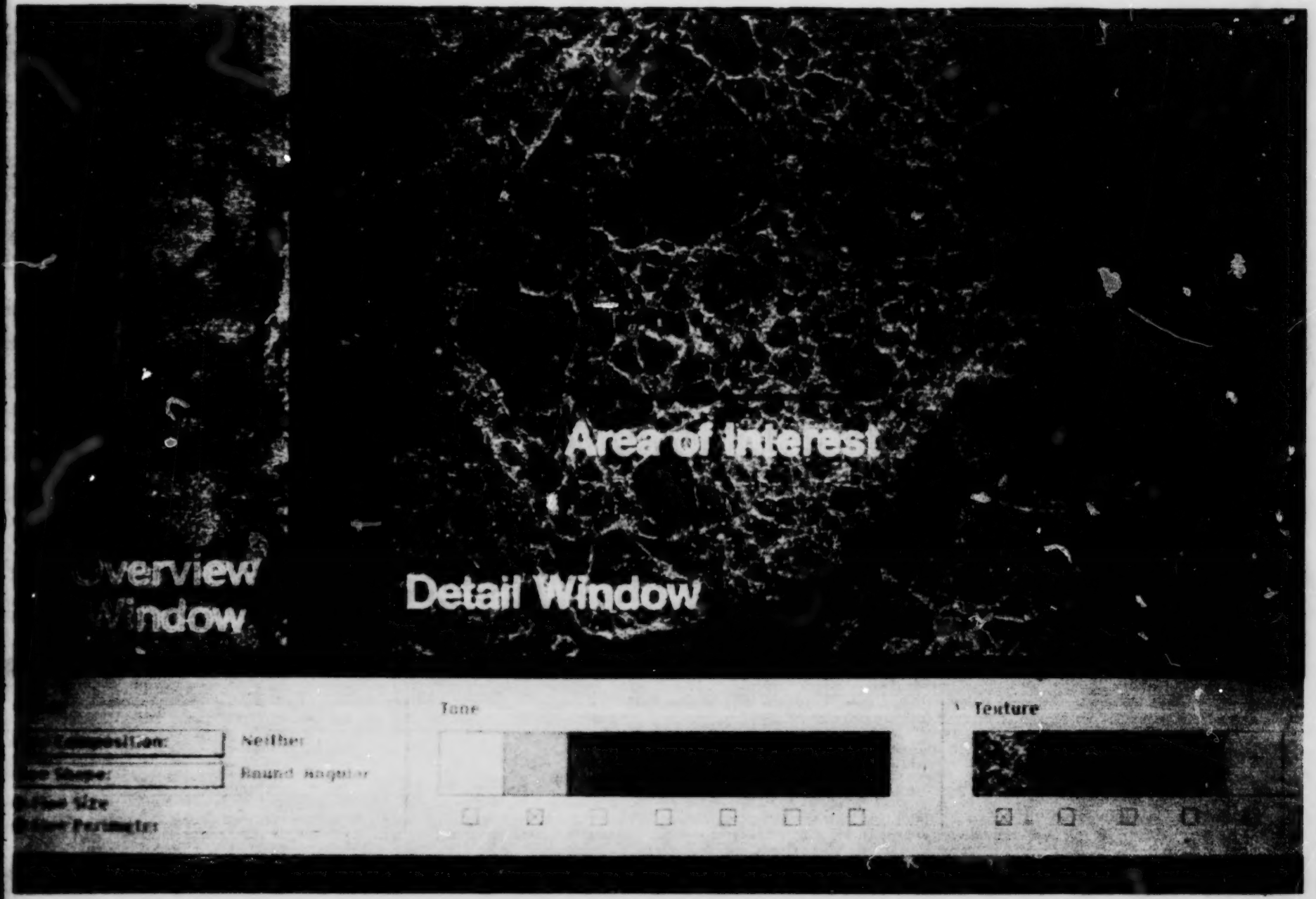

Figure 4. Floe Information, Tone and Texture Input Screen

Figure 5 shows the screen that is presented to the user requesting information on morphology and topography. Note again representative samples are utilised to solicit input on ridging, rafting, and rubble. The system also requires input on the absence or presence of openings and fractures.

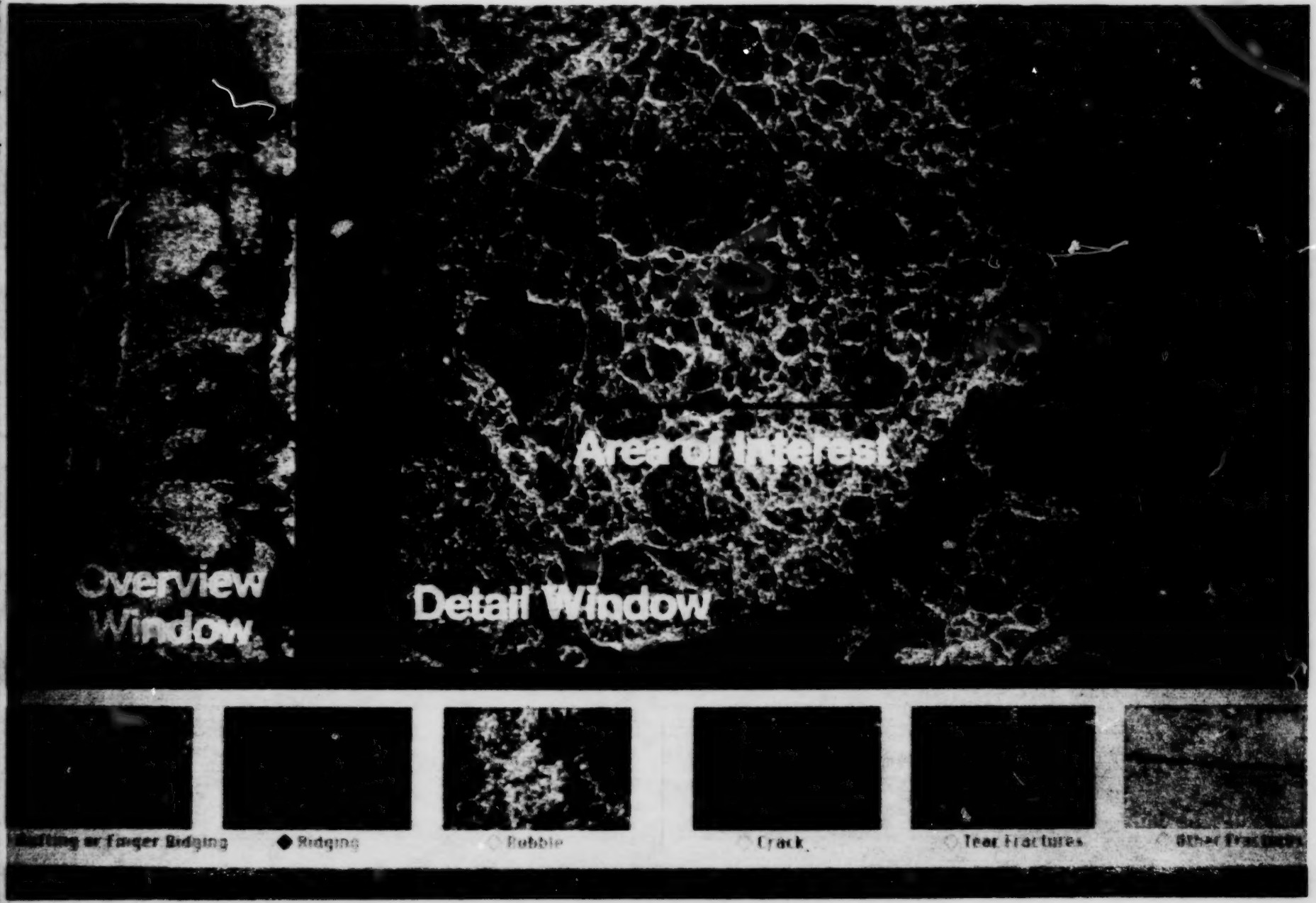

Figure 5. Morphology Topography Input Screen

Figure 6 shows the output of the system after user input has been completed. From the example shown here the system has concluded that the because the inner texture is mottled and the inner tone is grey, bright grey or bright, or very bright, the ice is multi year. This conclusion is supported by the supportive hypothesis (S) that large mottled grey floes are the most common forms of multi-year ice in the High Arctic and there is often a great deal of ridging and rubble around them. In addition the conclusion is confirmed by the precluder rules : bright to very bright inner tone and floes indicates this is not first year ice and mottled inner texture and floe sizes greater than 2 km indicates this is not new or young ice.

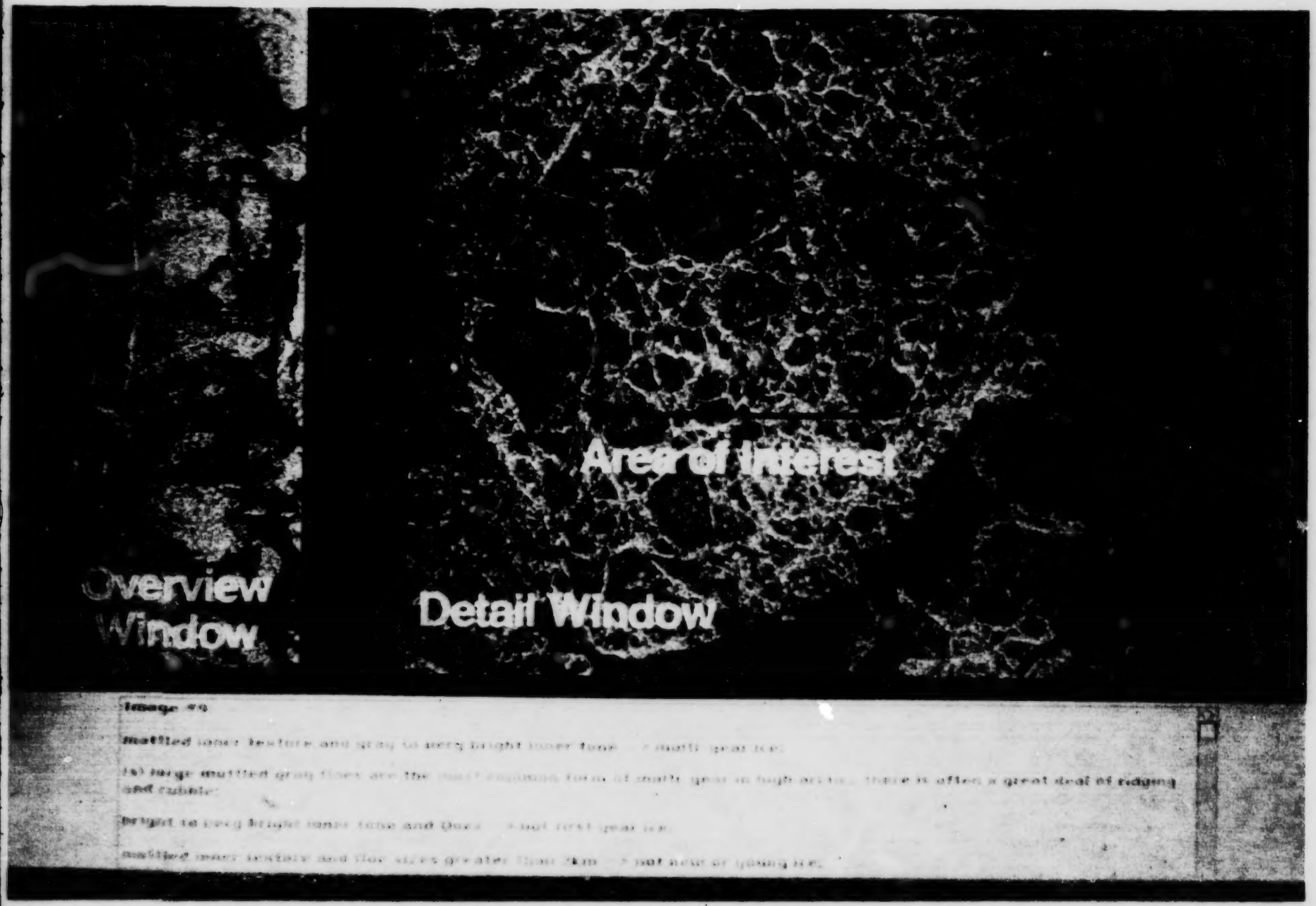

Figure 6. Expert System Output

In order to make the prototype more useful as a training tool, it was configured so that the user must go through a complete line of logical questioning before any output is presented. These questions are presented in an order thought to be a reasonable representation of the way that an experienced ice interpreter would proceed. A journal file is also created on the system. This file is used to record the path of decision making that the system took to arrive at a classification.

In many cases the system is able to classify the ice with a minimum amount of supplied information, sometimes requiring only three inputs from the user. This has implications for those researchers attempting to perform machine classification since it presents a way of reducing the amount of processing required.

A great deal more work is required to validate the accuracy of the classifications made by the system. At present it has been confirmed by at least one external expert that the system accuracy is about 75% for new, young, and first-year ice and about 85% accurate for old ice.

7. CONCLUSIONS

A knowledge based system for the interpretation of SAR images of sea ice has been developed that is capable of classifying SAR images based on a minimal set of feature information supplied by the user. The system contains approximately 100 rules and is capable of classifying SAR images based on a minimal set of feature information supplied by the user. The system runs on a small computer and can be used to assist non-experts make correct SAR ice interpretations. It also contains a SAR image database of representative ice types which can be displayed and used for training.

This prototype development focused on building and testing the general overall knowledge structures and rule sets for this application. Unlike other attempts to do fully automated machine processing of SAR images, a top-down, knowledge based approach has been taken to fully understand what important features and information are necessary for classification. This elicitation and structuring of the knowledge is seen as a necessary step in the development of training systems, Expert Assistants and fully automated ice classification systems. The techniques developed for the ice classification problem are also directly applicable to many other imaging problems requiring classification by experts.

The demonstration of the prototype to several user groups including Coast Guard and AES has resulted in a number of suggestions about how this technology should be applied in the future. The consensus of opinion is that the main applications are: for training; both initial and ongoing, for on-line help or assistance while in the field, and for pre-voyage briefing.

8. RECOMMENDATIONS

The prototype system was developed using the latest Expert System's technology operating on a small microcomputer and has established the value of this approach for those who require assistance with ice interpretation. This is particularly true now that Coast Guard is receiving SAR imagery from AES on a regular basis.

Currently the prototype system is limited in its domain of expertise: Basically only the Arctic winter ice conditions from a few selected areas have been incorporated into the knowledge base. The system has also not been fully validated by the end users with respect to system functionality, nor fully tested with exceptional case data.

The next evolutionary step in the development of this system is to take the system from the prototype stage to that of a pilot system which can be put into the hands of real users. These people, not the experts will ultimately use any resulting system, hence their input is essential.

Specific recommendations are:

- to expand the domain of the system's knowledge base to include, other geographic areas like the Gulf of St. Lawrence;
- to include other seasonal information particularly the summer melt conditions, to provide fine scale information on the characteristics of regions which have exceptional ice conditions;
- to perform a multilevel system evaluation with both experts and users This must include: testing with case data, debugging, and validation of the knowledge base and resultant system functionality and;
- to convert the development system into a pilot delivery system to be put into daily operations either on a ship or in an office environment.

The benefits of this development to Coast Guard and other marine operators are many:

Developing the prototype system has already contributed to a much better understanding of the knowledge required for ice classification particularly when classifications are made on the basis of a single sensor like SAR. The proposed project will further refine and standardize this knowledge.

The information base assembled can be used as the basis for training programs for CCG and others. Currently no standards for training or interpretation using SAR exist. In fact AES have expressed a keen interest in deploying the existing prototype system at Ice Central to help standardize their interpretations.

If the system is operated as an on-line assistant (assistant mode), it is possible to reduce ship's operating costs by reducing the need for ships to carry external ice experts. This role could then be assumed by Coast Guard officers.

Since ships do not always operate in ice and change operating regions and crews frequently, the on-line system could be used to reinforce basic training given to officers (tutorial mode). The system could also provide detailed information on the regional ice conditions in the areas where the ship is to be deployed. It would also be possible to include briefing information on the most recent ice conditions and trends in these areas (briefing mode).

Low cost workstations for training could easily be developed. These trainers would use both the knowledge and digital SAR image data base contained in the pilot system.

Proposed Developments

The following summarizes the development required to complete a pilot delivery system for operational testing. A prerequisite to the actual delivery of the pilot system is the expansion and evaluation of the prototype. INTERA has already established a methodology for incorporating and evaluating new information into the prototype system. It is anticipated therefore that this activity will proceed very rapidly.

Expansion of the Knowledge Base

It is proposed to expand both the number and scope of the rules used for ice classification since the prototype system is limited in its domain of expertise.

The current system only deals with Arctic winter ice conditions and the Arctic has been divided into 4 unique ice zones. The rule base will be expanded to include knowledge about:

- other regions, for example the Gulf of St. Lawrence, and other ice zones within the Arctic;
- ice conditions that exist during other times of the year. Of particular concern is the summer melt season when the radar imagery is at its worst for ice classification;
- more detailed or fine scale information about existing regions; and
- information on mixed ice types.

Adding this information to the prototype will result in a much more versatile system capable of preforming in real operational settings. The information contained in the system can also serve as the basis for training.

The procedure used to add to the knowledge base will follow the methodology established by INTERA for the existing prototype development. Ice experts will examine both new and existing radar data and new rule sets will be generated. These rules will be incorporated into the prototype which will be evaluated, tested, refined and rebuilt again. This procedure will continue until the system performs at a level consistent with the experts.

Expansion of The Image Base

It is recognized that while it is impossible to include all of the infinite number of possible ice conditions in any image base, the limited amount of imagery used for the prototype has resulted in many generalized assumptions being incorporated into the system. For example, most Arctic navigation takes place during the summer but the SAR coverage included in the current image base is almost non-existant.

It is proposed therefore, that a further detailed examination of new and existing image archive be conducted to expand and refine the rule base of system. Regions can be broken down into specific tactical locations for briefing purposes and detailed image data analysis will provide historic information for operational use. It is anticipated that new data available from the new AES aircraft will be made available for this development. Where possible corresponding visual ground truth information eg photographs should be used to complement the SAR image base.

By building up an extensive image base which covers all regions and seasons of interest interpretation of ice conditions will ultimately be handled much more efficiently with a greater level of confidence in the results due to the standardization of the interpretation procedures.

Pilot System

It is proposed that a pilot system be delivered to Coast Guard or other user for evaluation. The target system would consist of a small micro-computer (Mac II ci) with a 16" colour monitor. It is recommended that the completed prototype be converted into a conventional programming language to make it truly robust. This would also allow great flexibility in the user interface design. Hyper/SuperCard could be utilised to provide:

- -dynamic templates
- -movable/overlapping windows for use on smaller screens
- -scrolling images
- -custom menus
- -Macintosh model independence
- -hiding of rules
- -CD-ROM/Video disk access

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APPENDIX A

THE GENERATION OF DESCRIPTIVE CONSTRUCTS BASIC OF THE TASK OF ICE CLASSIFICATION AND DIFFERENTIATION

1.0 INTRODUCTION

The objective of the research was to refine a methodology to establish a knowledge base which will be employed in the development of a computer system planned to aid the process of ice classification and the teaching of ice classification procedures. Following preliminary research which involved two INTERA employees who discussed the process of ice classification based upon their perception of 25 Synthetic Aperture Radar (SAR) images, a method was designed to elicit from knowledgeable subjects information pertinent to ice analysis. This methodology involved subjects making comparisons between three images viewed in sequence in order to describe similarities and differences among them.

1.1 Session One: Method

Subjects:
Six INTERA employees served as subjects in the experiment.

Materials:
The materials used included the Participant Construct System (PCS), a set of computer programs developed by the Alberta Research Council for the elicitation and analysis of repertory grid data. INTERA provided 20 Synthetic Aperture Radar (SAR) images, four representing each of five ice classifications: open water/new ice, young ice, first year ice, rough/rubbled ice, and old ice. The resolution of the images was 24m/pixel and each image contained a box, approximately 5cm by 5cm, highlighting a particular portion of the image. The images were presented on the Triad Display software, developed by INTERA, and run on a PDP 11/73 equipped with a Parallax graphics board and Lynx 3-button trackball. The images were displayed on a 19" monitor.

Procedure:
There were three tasks in session one. For the first task of session one, subjects generated dimensions (constructs) used in ice classification with the aid of PCS, the Display software, and a subset of 10 SAR images. For each subject the subset of 10 images was randomly chosen from the 20 with the restriction that there be two images representative of each of the five ice types.

At the beginning of the session, the use of the triad software and details of entering the code names of the images on the panel were explained to the subjects. Subjects were told that they would be viewing ten ice images in total and that they would be viewing these in groups of three. They were familiarized with the trackball which enabled them to view successively any of the three images. Subjects were also briefed on the PCS system.

Subjects completed 20 trials. Each triad was chosen randomly with the restriction that no triad was repeated unless specifically requested by the subject. A triad consisted of viewing individually three of the SAR images from the subset of ten images and differentiating between them by following the PCS program. The PCS program asked subjects to indicate which image was different from the other two, how this image was different, how the other two images were similar, and thereby to generate a construct name,. Subjects were asked not to use actual ice classifications as responses to these questions. Subjects were permitted to view each image as often as they required. Subjects then rated each of the three images of the triad and also each of the remaining SAR images on the generated construct with the use of a five-point scale. The five-point scale displayed the construct name at one pole, to indicate the greatest abundance of this characteristic and the opposite of the construct name at the other pole of the rating scale to indicate the absence of this characteristic. The experimenter entered the construct name and ratings into the PCS program. Subjects were permitted to alter their ratings of the images until they were satisfied. If a subject was unable to generate a construct for a particular triad of images, she/he was allowed to go on to the next triad. If a particular triad resulted in the generation of more than one construct, that triad could be repeated if the subject wished. Subjects were permitted to use information from outside the boxed area on the image but were asked to base their final decisions on the area specified by the box.

All constructs generated by subjects during this task were compiled into a construct-pool. In addition of the rating grid showing how a subject rated each image on each construct, the experimenter recorded the trial number of presentation, the file name of each image in the triad, and the construct generated for each trial.

The second task in session one consisted of providing a brief definition of each construct generated.

The third task in session one consisted of rating, on a three point scale, the importance of each construct to the task of ice classification.

Results:
Subjects completed between 14 and 20 trials. Subjects generated a mean of 14 constructs (St. dev=1.9). Excluding repetitions and actual ice classifications, a pool of 31 unique constructs was formed. The subjects' definitions were divided into "high" and "low" categories. Low level definitions include information on the visible characteristics of each construct. High level definitions include information on the significance of each construct. The construct pool is included as Appendix B.

Upon completing the experiment, the subjects were asked to provide feedback on both the procedure and the materials used. Their concerns focused on the materials, specifically on some of the images chosen and the location of the box on some images. Other concerns included the limited geographical location and seasonal representation in the image set.

1.2 Session Two

The recommendations provided by the subjects during session one were taken into consideration and a new set of 10 images was compiled by the project coordinator for use in session two. This set contained five of the images used in session one along with five new images. There were two images from each of five ice types: open water/new ice, young ice, first year ice, rough/rubbled ice, and old ice. The new image set represented a wider range with respect to geographical location and seasons The box size and location were altered for each image such that the indicated area was more homogeneous in ice type. Session two was designed to ascertain the amount of agreement between experts when rating identical images over each of the 31 constructs.

Method

Subjects:
Five of the individuals who served as subjects for session one also served as subjects for session two. The sixth subject from session one was unavailable for the second session.

Materials:
With the exception of changes made to the image set, all materials from session one were used again in session two.

Procedure:
A copy of the construct pool, on which the constructs had been listed in random order, was given to each subject the day before they were to participate in session two. Subjects were asked to familiarize themselves with all of the constructs and their definitions. At the beginning of the second session, subjects were informed of the changes made to the image set and were permitted to view each of the images.

In session two, subjects rated the set of 10 SAR images on all of the constructs from the construct pool. Subjects rated all ten images on the first construct, then rated all images on the second construct and so on down the list of 31 constructs, thus enabling subjects to alter their ratings as they were prone to do in session one.

For this session, the PCS program was not used to generate constructs; instead it was used to tally the subjects' image rating on a five point scale. Again, the subjects operated the triad software and trackball while the experimenter entered their ratings on the PCS program. subjects were permitted to rate the images in any order they desired. as in the first session, subjects were permitted to view each image as often as they wished and to alter their ratings until they were satisfied. They were also informed again that while they could use information from outside the boxed area, their final decisions were to be based on the area outlined by the box.

After rating the images on each of the constructs, subjects were asked to rate, on a three point scale, the importance of each construct to the task of ice classification. Finally, subjects classified the boxed area of each image according to ice-type and provided a confidence rating of their classification on a three-point scale.

Results:

Subjects rated ten images on each of 31 constructs. Of the total of 310 ratings given on the five-point scale, subjects were in complete agreement on 104 of these (33.5%). The majority of agreements, 87 of the 104 (83.7%), represented instances in which a construct was judged as not present. The remaining agreements, 17 of 104 (16.3%), were all cases in which a construct was seen as being most strongly represented. That is, they were instances in which the highest rating on the five-point scale had been useed. The five subjects were never in agreement for cases in which a construct was judged as present in an intermediate quantity. This can be seen in Table 1.

There was one instance of complete agreement among subjects on the importance of constructs to the task of ice classification. All subjects agreed that the construct "high-low concentration" was somewhat important. Fourteen of the 31 constructs were given a mean rating which placed them between very important and somewhat important. There were nine constructs which no subject judged to be very important. Table 2 indicated the importance ratings for each subject as well as the mean importance rating and frequency of agreement.

All subjects classified four of the ten images identically. Both images representing the category of old ice were classified identically by all subjects. One of the images from each the open water/new ice category and the first year ice category were agreed upon by all subjects. The confidence ratings were on a three point scale with one representing most confident. As can be seen from Table 3, the overall mean confidence ratings for each image was less than 2.0 in each instance. For three images, the overall confidence rating was 1.0 most confident. Two of these three were images for which all subjects agreed on the ice classification.

Discussion:
Session one resulted in the generation of 31 constructs and the definition of each construct.

The results from session two show that subjects are more likely to be in agreement in cases where a construct is either absent completely or present to the greatest extent. Subjects were never in agreement for intermediate ratings. While subjects only generated identical importance ratings for one construct, there were 14 constructs which were judged overall, to be more important than the others. Both of these results have implications for the development of a weighting scale for constructs in any future computerized system.

While subjects were for the most part very confident of their classifications of ice, they disagreed on six of 10 images with respect to the AES classifications. This may reflect varying degrees of experience and/or differences in ice-analysis training.

The results and feedback from subjects indicate that some of the inter-subject variability may arise from methodological problems. For example, subjects were not in agreement with the wording of some of the construct definitions, nor with some of the AES classifications assigned to the images.

APPENDIX B

CONSTRUCT POOL

1. DISTINCT FEATURE - NO DISTINCT FEATURE

low:

high: Features appearing distinct indicate age, formation process, interaction, dynamics. Featureless ice is usually very old or very young.

2. DIVERGENCE-NON-DIVERGENCE

low: The open water is observed as dark tone in linear features. In many cases there is a variation in the tone across a fracture as new ice forms.

high: Open water, fractures and leads are generated by diverging motion.

3. LACY RIDGE PATTERN -NO LACY RIDGE PATTERN

low: Bright ridge features against the dark background of smooth ice creates a pattern over scales of tens of kilometres.

high: Most commonly observed in young ice. The dark smooth background usually exhibits a "transparent appearance".

4. SMOOTH SURFACE-ROUGH SURFACE

low: A rough surface has a wide variation in the tone over an area and has a significant variation in the tonal quality between adjacent pixels. A smooth surface has a narrow variation in the tone over an area. A rough surface appears abrasive to the touch, whereas a smooth surface appears smooth to the touch.

high: Rough surfaces are observed for rubbled ice areas where floes have been fractured and piled over an area. Smooth surfaces commonly indicate ice which has frozen under quiescent conditions has not experienced any dynamic motion.

5. HIGH CONTRAST-LOW CONTRAST

low: Contrast is the variation of the tone in an image. High contrast indicates a wide spread between the darkest pixel tone and the lightest pixel tone. For low contrast images the spread between darkest and brightest tones is diminished.

high: Flat young ice with newly formed ridges will usually have high contrast. Ridges produce bright return whereas flat young ice produces dark return. Multi-year ice usually has low contrast since the brightness of the ridges has diminished due to weathering and the background has brighten due to changes in the crystal structure of the ice.

6. ICE EDGE RUBBLE-NO ICE EDGE RUBBLE

low: An area of very bright fine texture. The shape of this feature is always long, in the direction of the ice edge.

high: Found only at the edge of the ice. The ice edge forms the demarcation between an area of open water and sea ice of any form, whether fast of drifting. The ice edge is in the order of tens of kilometres in length and the area is in the hundreds of square kilometres in area.

7. BRIGHT TONE-DARK TONE

low: Tone is measured by individual pixel or for an area of pixels. The tone indicates the magnitude of the radar return. A bright tone indicates high return whereas dark tone denotes lack of return.

high: The return is a function of the type of ice and/or the physical nature of a feature. Ridges give a bright return due to geometry and multi-year ice gives a bright return due to the electro-magnetic properties of the ice. Open water gives no return since all energy is absorbed.

8. ANGULAR FLOES - NO FLOES

low: Ice floes which can be observed have sharp angular shapes like polygons. The edges are usually defined by changes in tone and not likely by ridges.

high: Angular ice floes are usually observed for first-year ice and younger. Angular ice floes indicate recent motion since sharp edges have not yet experienced sufficient motion to cause wearing of edges.

9. FINE TEXTURE-/COARSE TEXTURE

low: The texture refers to the variation of the pixel tone or brightness. Whereas tone is measured for a single element, texture is a spatial quality comprised of many elements of varying tone. Fine texture refers to minor variation of tone over a scale of a few pixels. These could be variation of the tone over a scale of a number of pixels. Course texture has the appearance that it could be rough to the touch.

high:

10. ICE EDGE - NO ICE EDGE

low: A distinct break in the ice is a major fracture or an ice edge.

11. HOMOGENEOUS TONE-INHOMOGENEOUS TONE

low: Homogeneous tone is consistent and uniform tone from pixel to pixel in any direction. The tone can vary from bright to dark. Inhomogeneous tone is a variation in the tone in one or all directions.

high: Homogeneous tone usually observed for smooth flat ice which has formed under quiescent conditions. The level of the tone varies with the development of the ice. Inhomogeneous tone is observed in continuously opening leads as new ice forms and ages.

12. MUCH RUBBLE-NO RUBBLE

low: A heavily rubbled/ridged area has a very bright coarse texture. Areas are in excess of hundreds of metres in diameter.

high: Rubble is broken ice forced up by compressive ice pressure. Usually observed along coastal areas where high compressive forces are observed.

13. DEFINED FLOE-INDETERMINANT FLOE

low: A floe is a clearly identifiable area of uniform tone and texture surrounded by a different tone and texture.

high: Multi-year ice floes usually show up very bright in the dark background matrix of first-year ice.

14. ACTIVE FREEZING - NO ACTIVE FREEZING

low: Identified by bright tone in the lead.

high: Indicates the age of the lead, and the weather in the past 12-24 hrs. There may be gradations in the tone as a result of the variation in the stage of development as the fracture or lead forms.

15. MOTTLED TEXTURE-NO MOTTLED TEXTURE

low: Texture with a speckled characteristic.

high: Texture commonly observed for multi-year ice floes.

16. FORMED IN A LEAD-NOT FORMED IN A LEAD

low: Ice formed in a lead can have a rough surface due to winds blowing.

high: This often relates to a lead opening caused by strong winds interacting with the ice surface.

17. LEADS-NO LEADS

low: Leads are distinguished by their long linear shape and very wide extent. They have a dark tone. This tone may be brighter but is often very dark. Leads have typically little texture, except for obvious pieces of ice floating in them.

high: The presence of leads indicates ice motion, usually pure divergence.

18. BRIGHT ON DARK - DARK ON BRIGHT

low: Predominantly bright on dark = as in the lacy pattern with smooth surface (darker) between bright ridges (younger, newer). Predominantly dark on bright = older, bright floes within newer smooth (darker) ice or open water.

19. RIDGING-NO RIDGING

low: Ridges are bright linear features over scales usually less than a kilometre. New ridges appear as bright tone against a dark background.

high: Ridges are generated when ice sheets converge. Ridges are commonly created in ice classes younger than, and including first-year ice. Ridges on bright ice are often lost because they are white on white. This is an instrument artifact and can be "perceived" if you know what to look for, as residual texture in the bright tones.

20. CONSOLIDATED - NON-CONSOLIDATED

low:

high: Refers to ice that has been frozen or refrozen to form a coherent ice formation.

21. DEFINED RIDGE PATTERN-NO DEFINED RIDGE PATTERN

low: Bright ridge features against the dark background of smooth ice creates a pattern over scales of tens of kilometres.

high: Ridge pattern indicates compressive forces over a large area. A lack of ridges, especially for smooth flat ice, indicates an absence of compressive forces.

22. FRACTURES-NO FRACTURES

low: A fracture appears as a dark tone, linear feature with sharp distinct edges.

high: A fracture is a crack in the ice which has opened to expose open water which has not yet refrozen. The fracture can be caused by a tensile diverging action or a shearing action. Fractures indicate that the ice has very recently experienced motion. The nature of the fracture can give an indication of ice thickness and age.

23. ROUNDED FLOES - NO FLOES

low: An area comprised of uniform tone and texture which is predominantly circular.

high: In a dynamic regime thicker ice floes wear at the edges due to interaction with other floes. As a result sharp protruding edges are worn giving clear circular appearance.

24. MELT PONDS - NO MELT PONDS

low: Melt ponds appear as circular areas of uniform tonal quality. Ponds are in the order of metres in diameter.

high: Are created on the surface of floes as a result of a thaw. Resultant water unable to drain off surfaces collects in ponds. Most often observed on multi-yr ice floes.

25. RAFTING-NO RAFTING

low: Rafting appears as a bright linear feature against the smooth dark tone background.

high: Is the overthrusting of one ice sheet by another. There is a predominance of thrusting in one direction. Usually observed for younger thin ice types. Rafting indicates compressive forces in the ice.

26. FINGER RAFTING-NO FINGER RAFTING

low: Rafting appears as a bright linear feature against the smooth dark tone background. There is a sine wave geometry on the scale of hundreds of metres.

high: Is the overthrusting of one ice sheet by another. Occurs in young thin ice. The overtrusting alternates between sheets to create an interlocking finger appearance. Usually observed for younger thin ice types. Rafting indicates compressive forces in the ice.

27. HOMOGENEOUS TEXTURE-INHOMOGENEOUS TEXTURE

low: Homogeneous texture is consistent uniform texture with an area of measurement. The texture can vary from coarse to fine. Inhomogeneous texture is a variation in the texture with the same area of measurement.

high: Homogeneous texture usually observed with a floe and for larger areas where ice developed at a uniform rate. Inhomogeneous texture usually observed for ice that forms at different times, rates, and under varying circumstances.

28. 10/10 CONCENTRATION - 0/10 CONCENTRATION

low: The total quantity of an area covered by ice. The coverage is expressed as tenths. The ice is usually assumed for any area which has tone and open water for all black tone areas.

high: Concentration of 10/10 indicates complete ice coverage and 0/10 indicates open water. Total 10/10 concentration commonly observed under winter ice conditions and zero concentration under summer ice conditions.

29. DYNAMIC-NON-DYNAMIC

low: Ice formed in dynamic, windy conditions will have a rougher surface than ice formed in a windless, protected area.

high:

30. WEATHERED RIDGES-NO RIDGES

low: Weathered ridges appear as bright linear features against a darker tone background. The tone of weathered ridges is diminished from that of new ridges.

high: Weathered defines the age of ice ridges. The bright return of a ridge is caused by the physical dimensions of the fractured ice floes (which act as corner reflectors). New ridges have sharp edged blocks which give relatively good radar returns. In many instances the parent ice is flat and smooth which produces a dark tone. As a result the bright new ridges are very prominent against a dark background. As the ridges are exposed to environmental conditions the sharp edges are weathered causing smoother rounded edges on ice blocks which produce less radar return intensity. Furthermore, the surrounding parent ice is usually subjected to weathering and dynamic forces which damage the flat surface and cause a general increase in the background final quality.

low: They are usually bright linear features against a dark background. Very similar in appearance to normal pressure ridges, except that they are straight in nature over scales of kilometres.
high: Usually observed in first-year ice and near coastal areas.

APPENDIX C

REPERTORY GRID ANALYSIS

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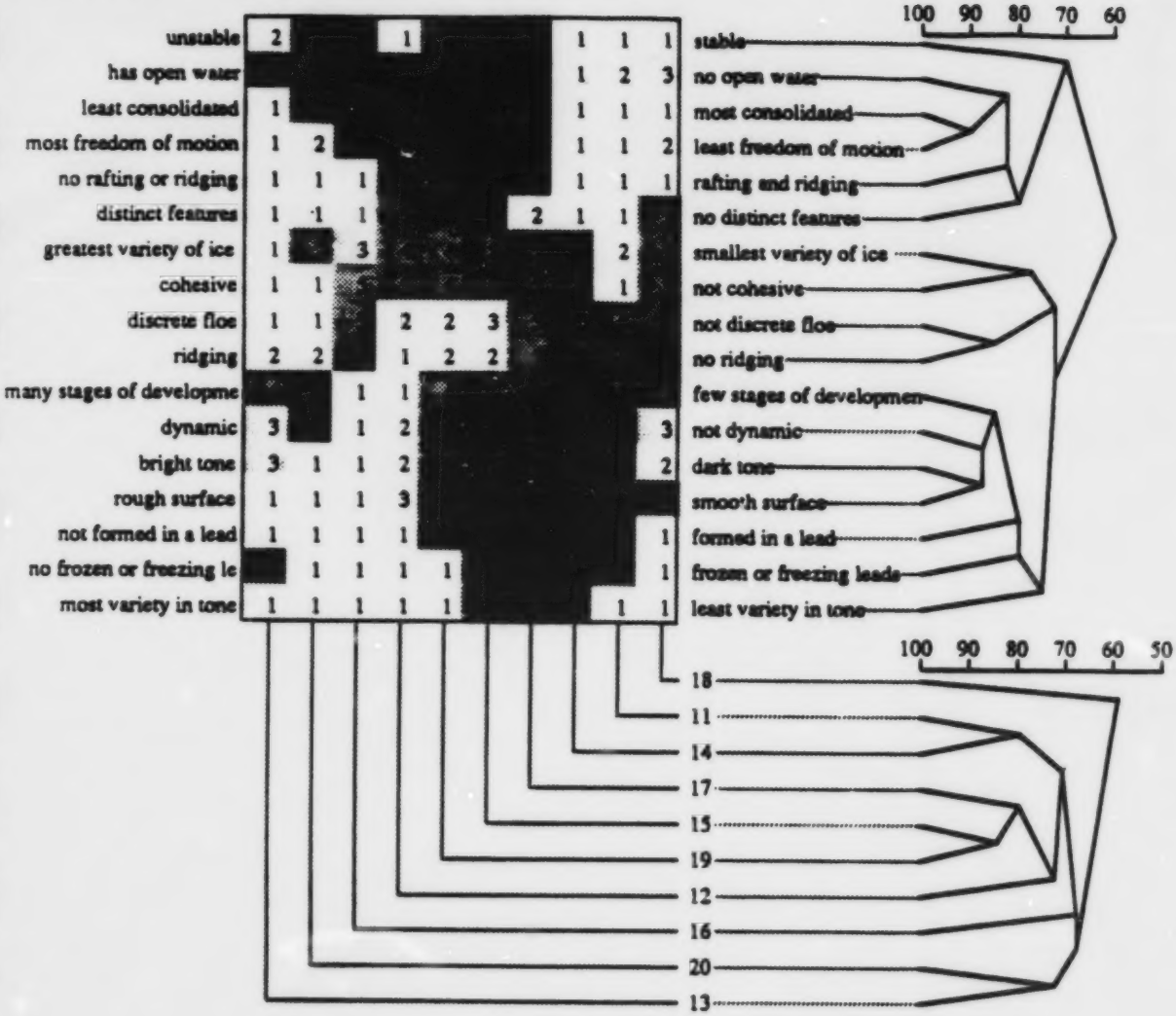

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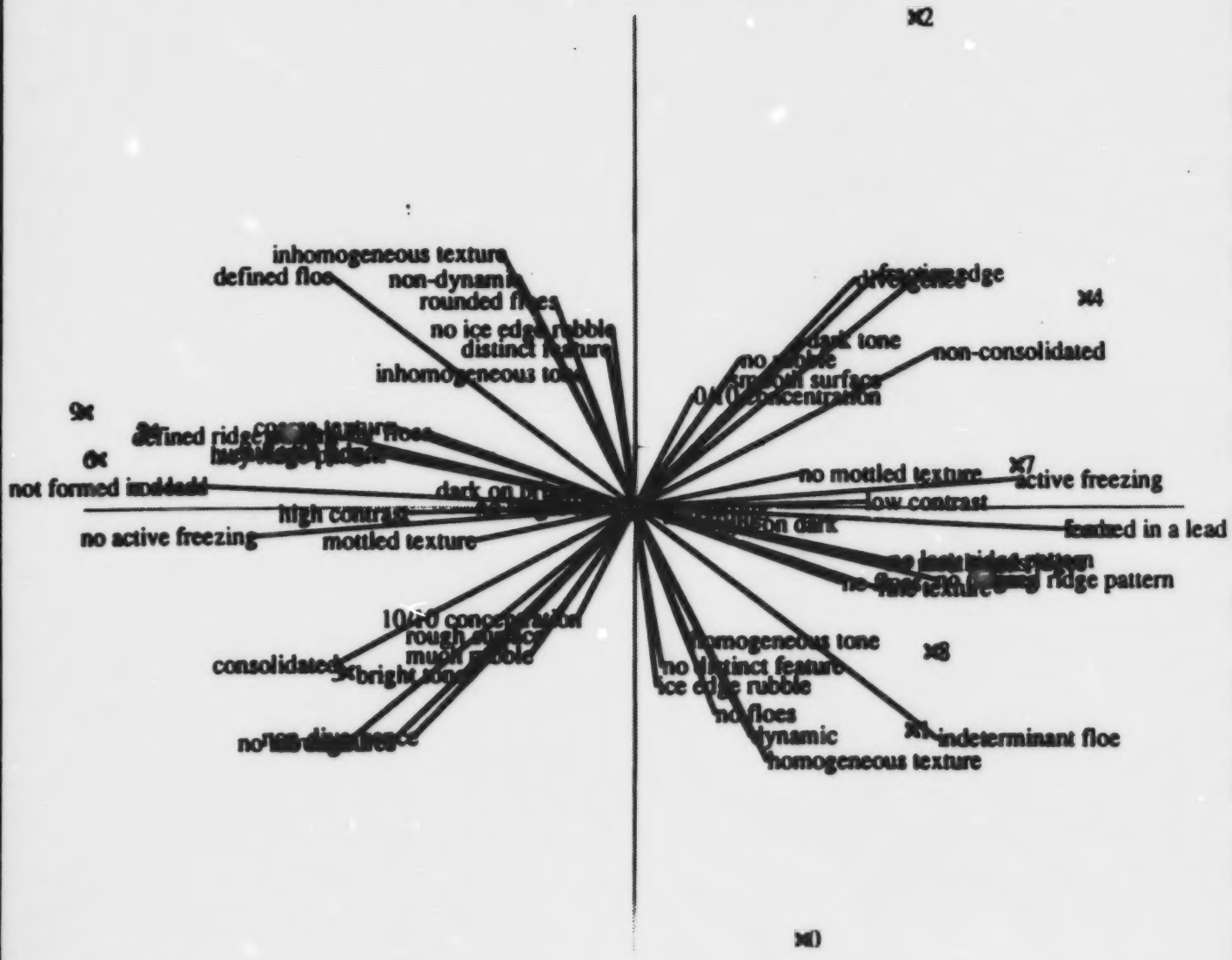

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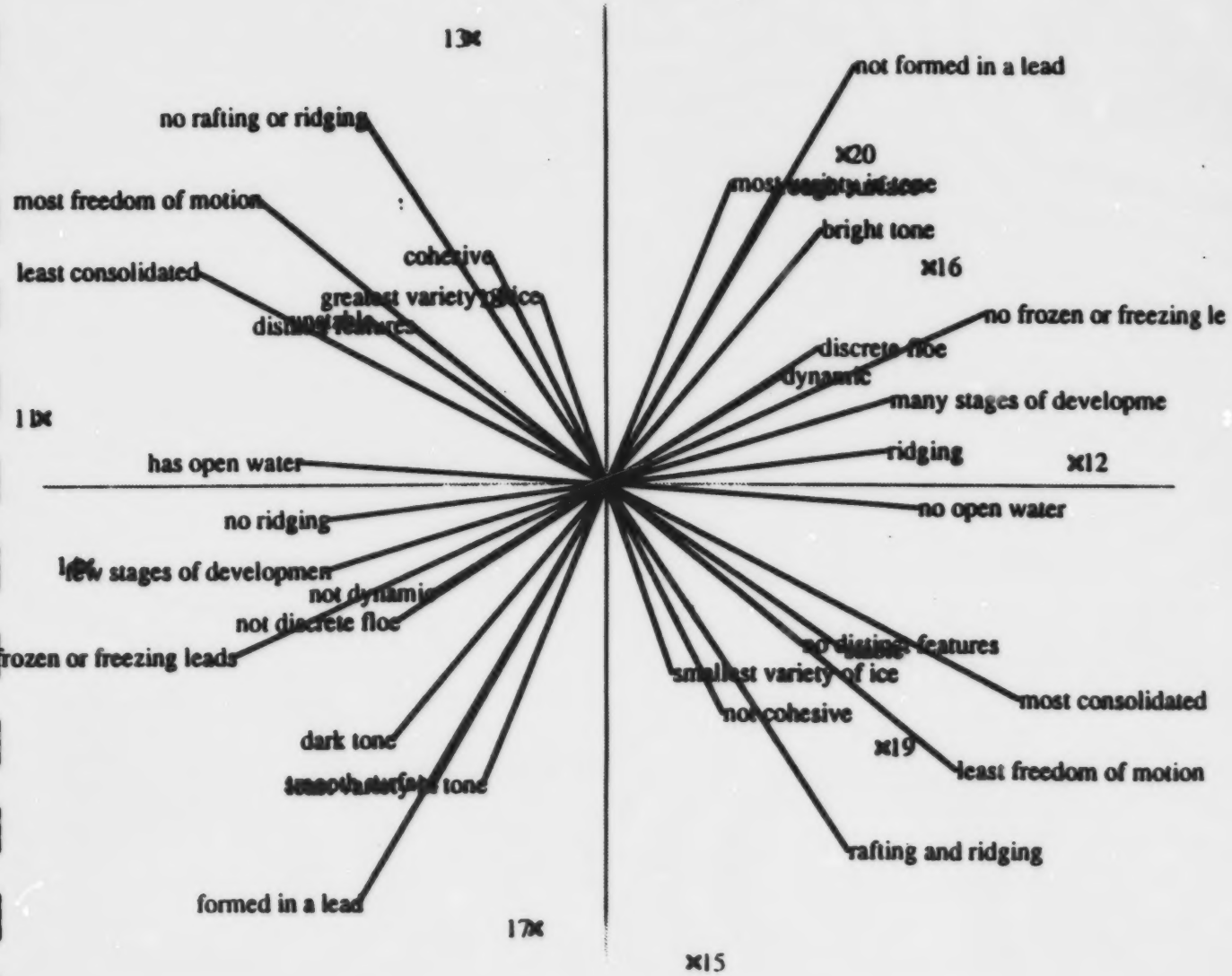

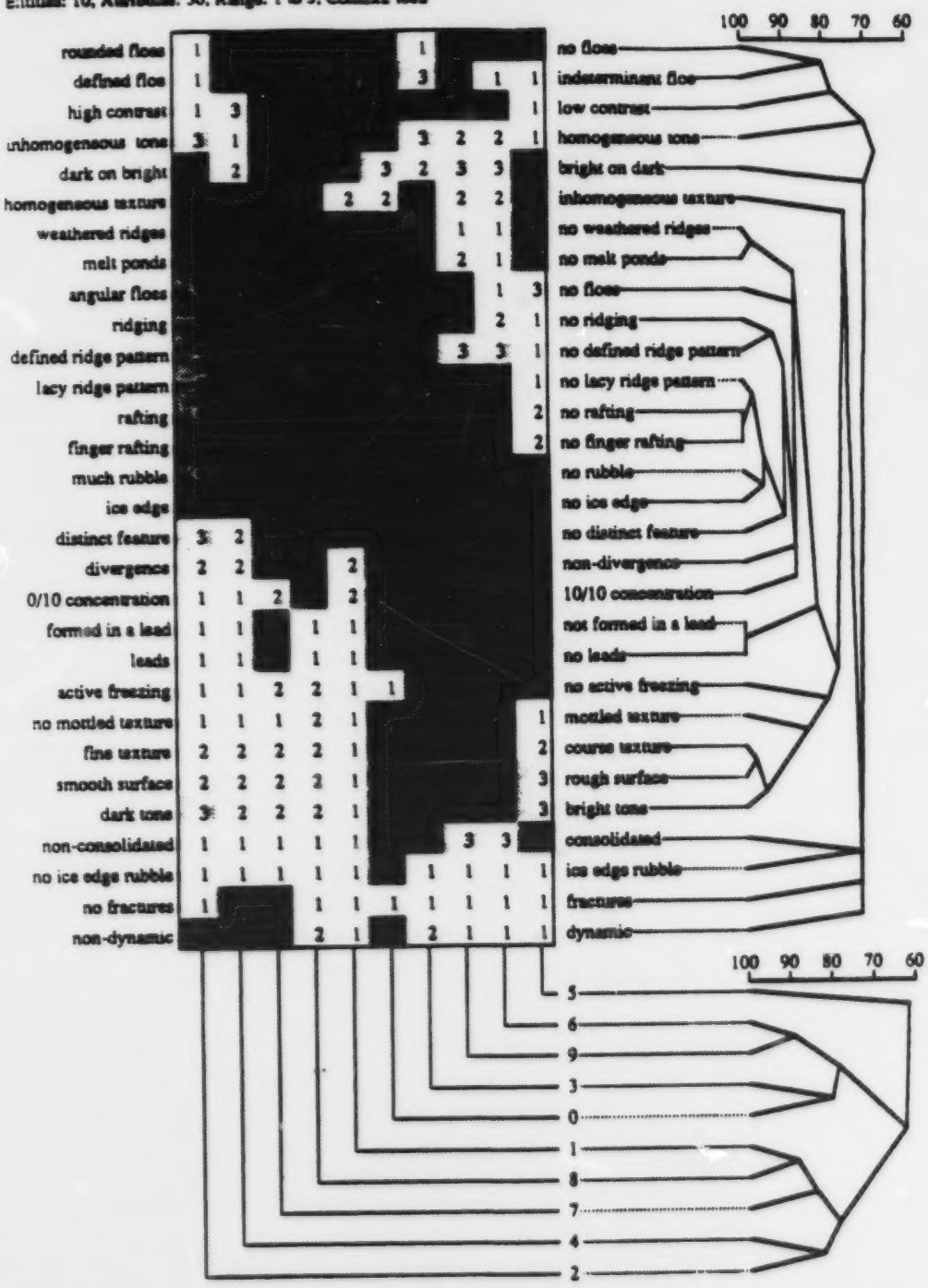
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rounded floes
defined floe
high contrast
inhomogeneous tone
dark on bright
homogeneous texture
weathered ridges
melt ponds
angular floes
ridging
defined ridge pattern
lacy ridge pattern
rafting
finger rafting
much rubble
ice edge
distinct feature
divergence
0/10 concentration
formed in a lead
leads
active freezing
no mottled texture
fine texture
smooth surface
dark tone
non-consolidated
no ice edge rubble
no fractures
non-dynamic
no floes
indeterminate floe
low contrast
homogeneous tone
bright on dark
inhomogeneous texture
no weathered ridges
no melt ponds
no floes
no ridging
no defined ridge pattern
no lacy ridge pattern
no rafting
no finger rafting
no rubble
no ice edge
no distinct feature
non-divergence
10/10 concentration
not formed in a lead
no leads
no active freezing
mottled texture
course texture
rough surface
bright tone
consolidated
ice edge rubble
fractures
dynamic
100 90 80 70 60
5
6
9
3
0
1
8
7
4
2

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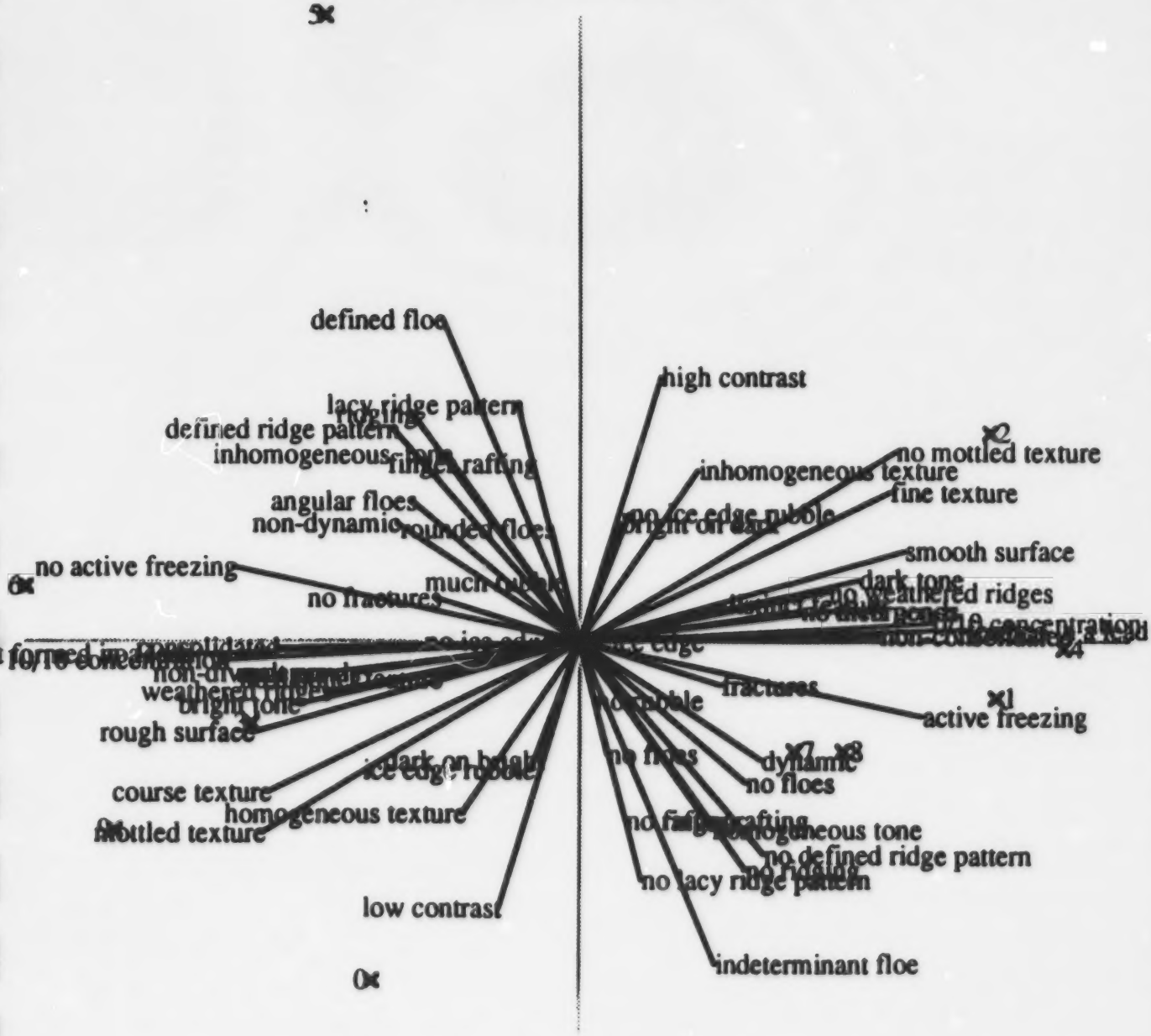

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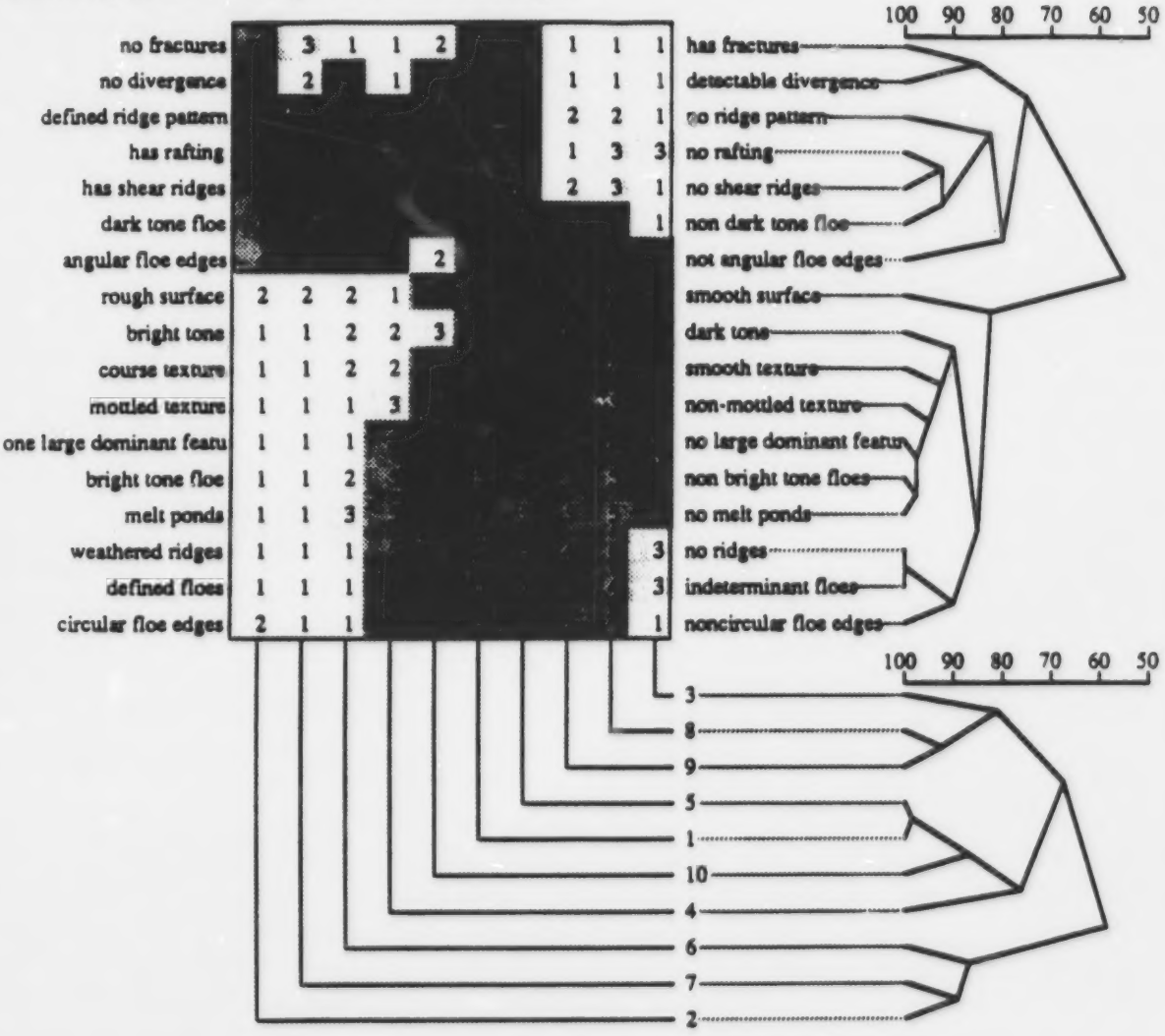
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no fractures 3 1 1 2 1 1 1 has fractures
no divergence 2 1 1 1 1 detectable divergence
defined ridge pattern 2 2 1 no ridge pattern
has rafting 1 3 3 no rafting
has shear ridges 2 3 1 no shear ridges
dark tone floe 1 non dark tone floe
angular floe edges 2 not angular floe edges
rough surface 2 2 2 1 smooth surface
bright tone 1 1 2 2 3 dark tone
course texture 1 1 2 2 smooth texture
mottled texture 1 1 1 3 non-mottled texture
one large dominant featu 1 1 1 no large dominant featu
bright tone floe 1 1 2 non bright tone floes
melt ponds 1 1 3 no melt ponds
weathered ridges 1 1 1 3 no ridges
defined floes 1 1 1 3 indeterminant floes
circular floe edges 2 1 1 1 noncircular floe edges
100 90 80 70 60 50
3
8
9
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10
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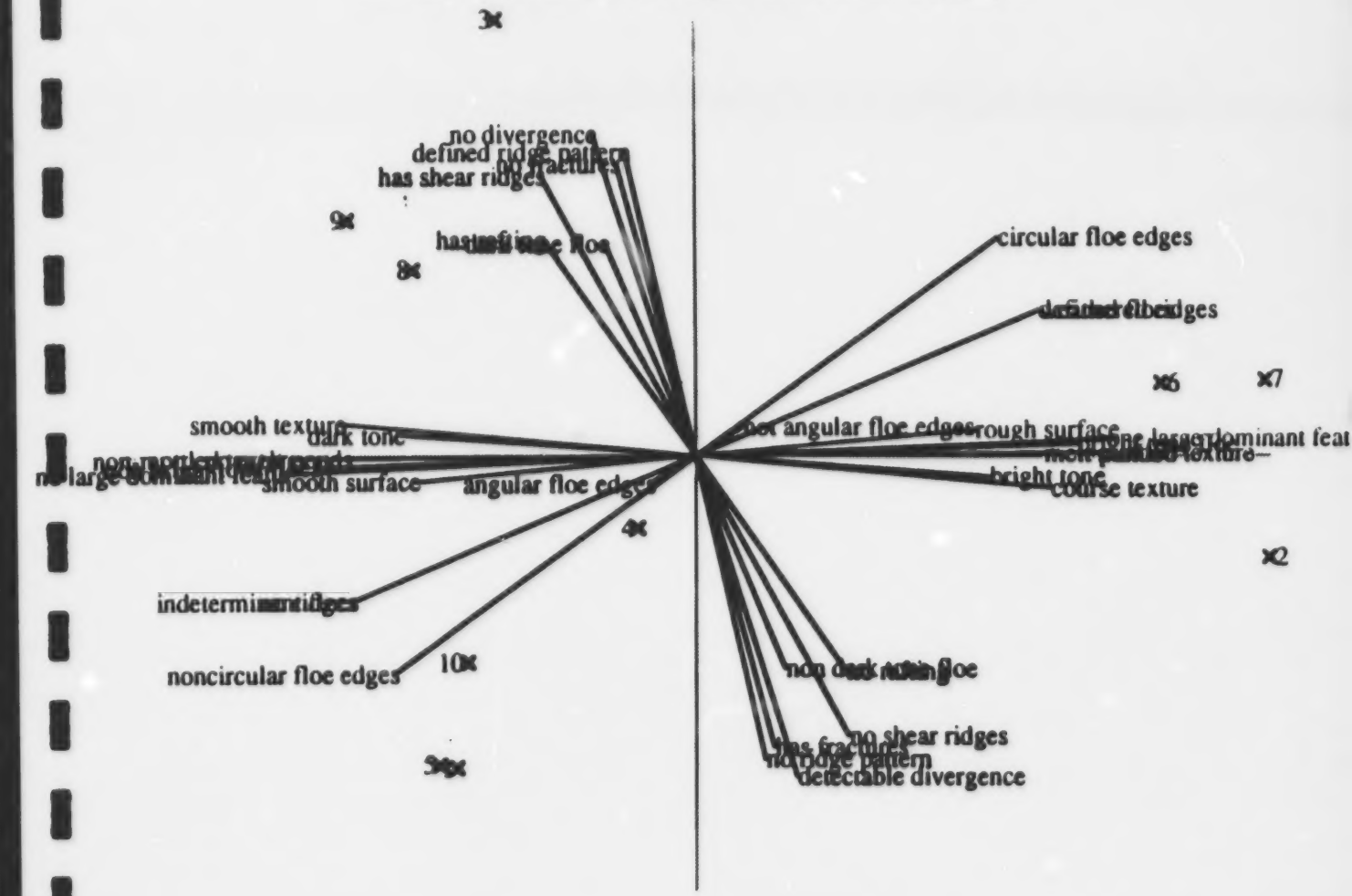
6
7
2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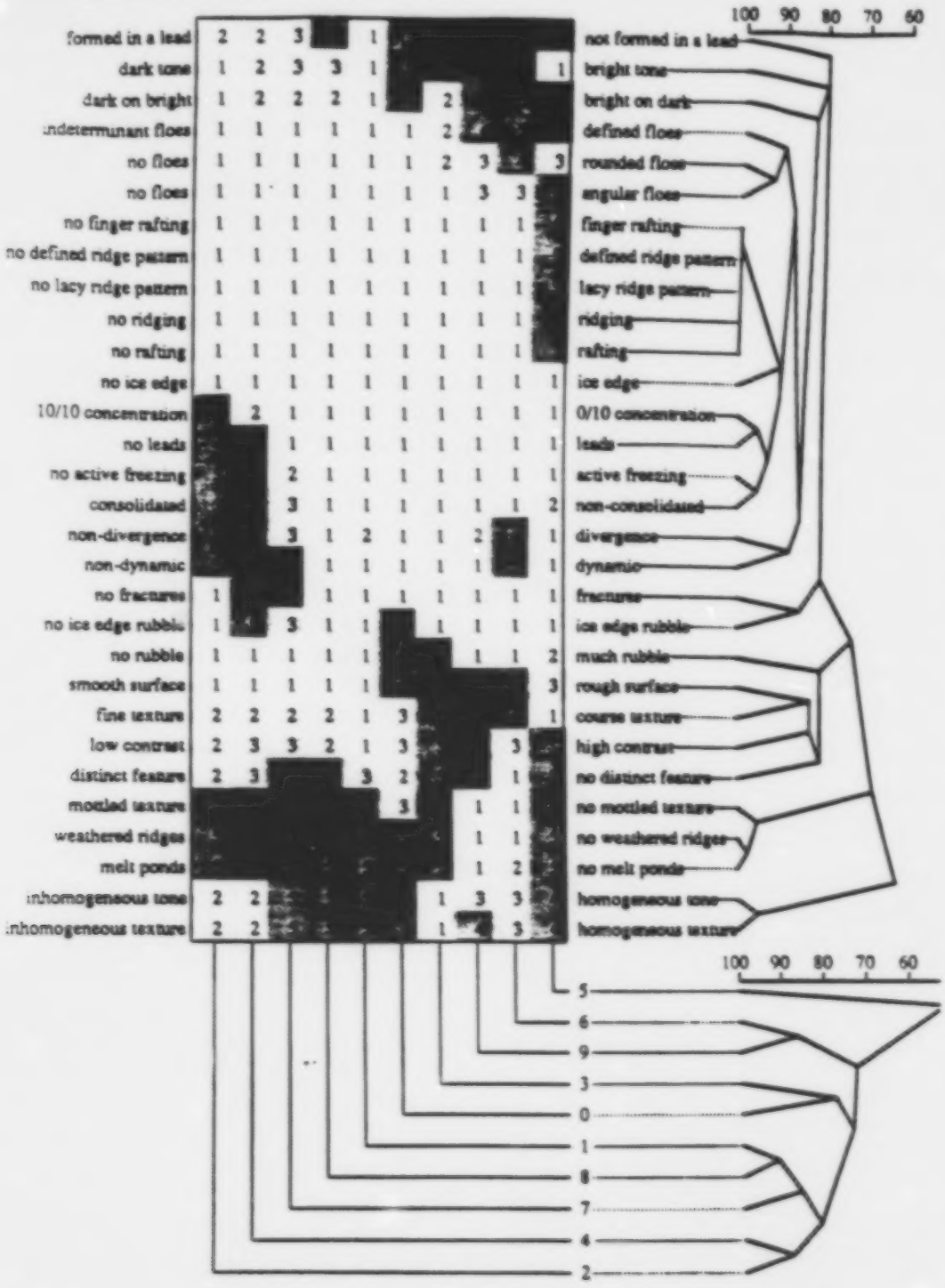
3
no divergence
defined ridge pattern
has shear ridges
9
8
circular floe edges
6
7
smooth texture
dark tone
smooth surface
angular floe edges
rough surface
bright tone
course texture
4
2
noncircular floe edges
10
no shear ridges
detectable divergence
5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formed in a lead
dark tone
dark on bright
indeterminant floes
no floes
no floes
no finger rafting
no defined ridge pattern
no lacy ridge pattern
no ridging
no rafting
no ice edge
10/10 concentration
no leads
no active freezing
consolidated
non-divergence
non-dynamic
no fractures
no ice edge rubble
no rubble
smooth surface
fine texture
low contrast
distinct feature
mottled texture
weathered ridges
melt ponds
inhomogeneous tone
inhomogeneous texture
not formed in a lead
bright tone
bright on dark
defined floes
rounded floes
angular floes
finger rafting
defined ridge pattern
lacy ridge pattern
ridging
rafting
ice edge
0/10 concentration
leads
active freezing
non-consolidated
divergence
dynamic
fractures
ice edge rubble
much rubble
rough surface
course texture
high contrast
no distinct feature
no mottled texture
no weathered ridges
no melt ponds
homogeneous tone
homogeneous texture
100 90 80 70 60
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2

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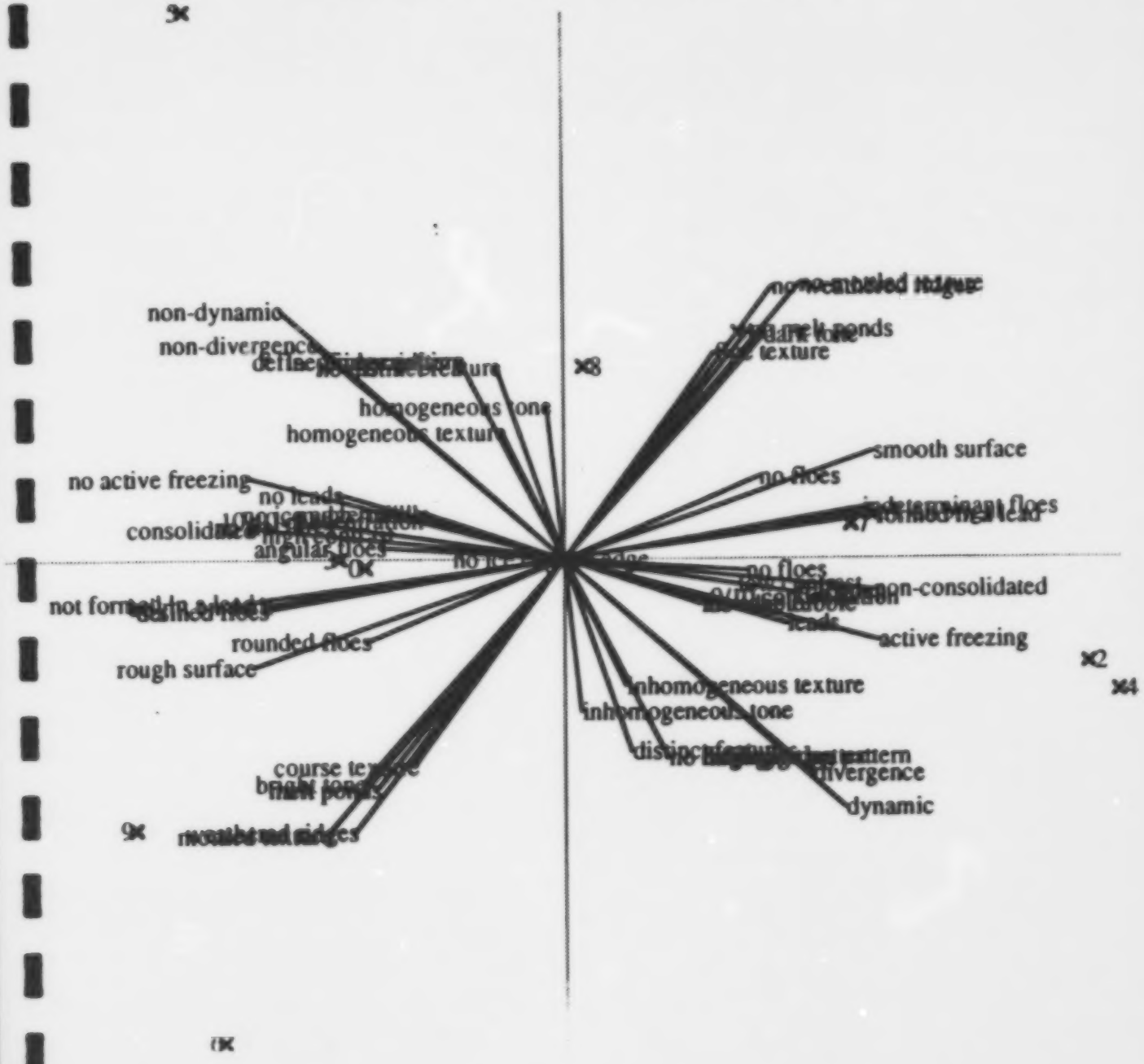

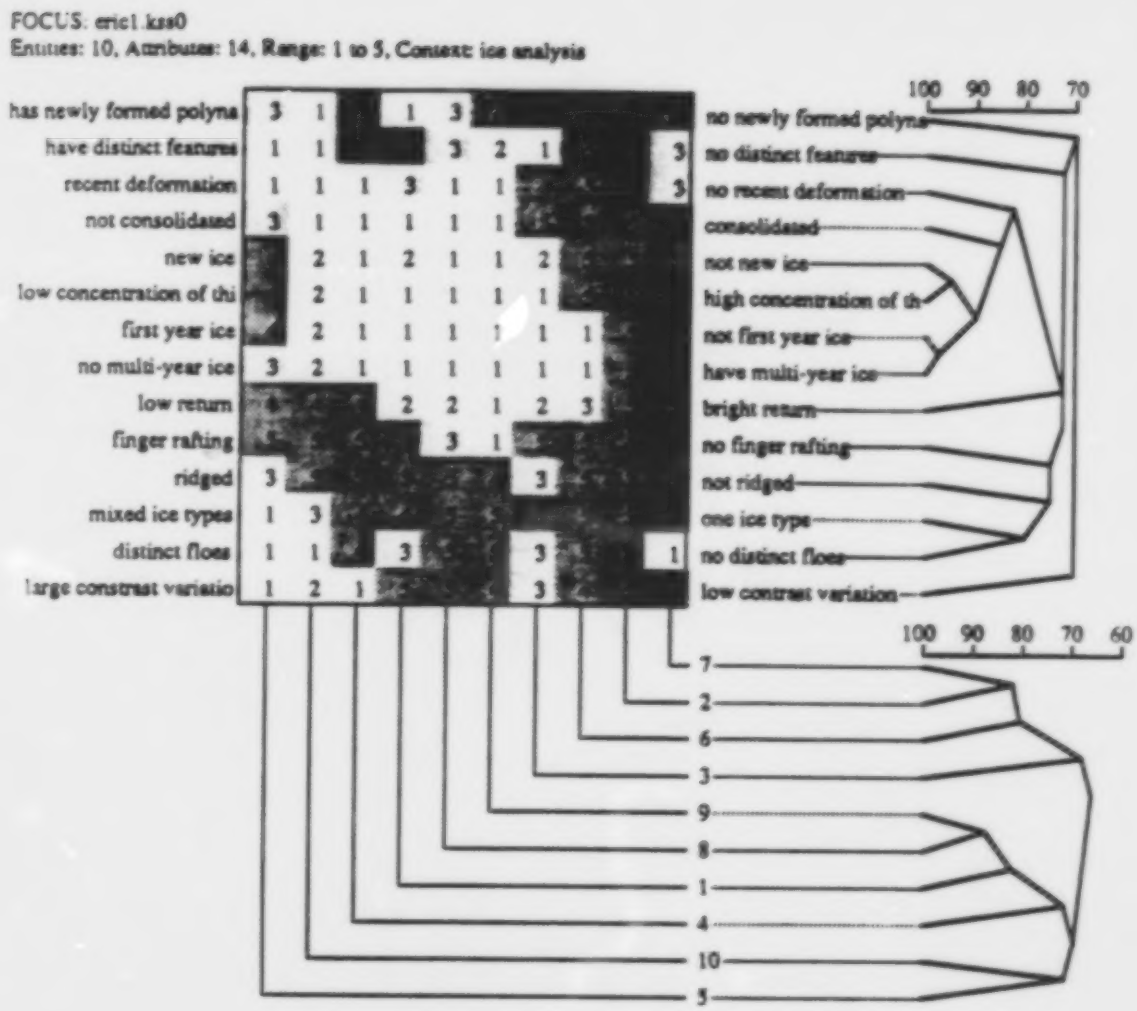
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has newly formed polyna
have distinct features
recent deformation
not consolidated
new ice
low concentration of thi
first year ice
no multi-year ice
low return
finger rafting
ridged
mixed ice types
distinct floes
large constrast variatio
no newly formed polyna
no distinct feature
no recent deformation
consolidated
not new ice
high concentration of th
not first year ice
have multi-year ice
bright return
no finger rafting
not ridged
one ice type
no distinct floes
low contrast variation
100 90 80 70
100 90 80 70 60
7
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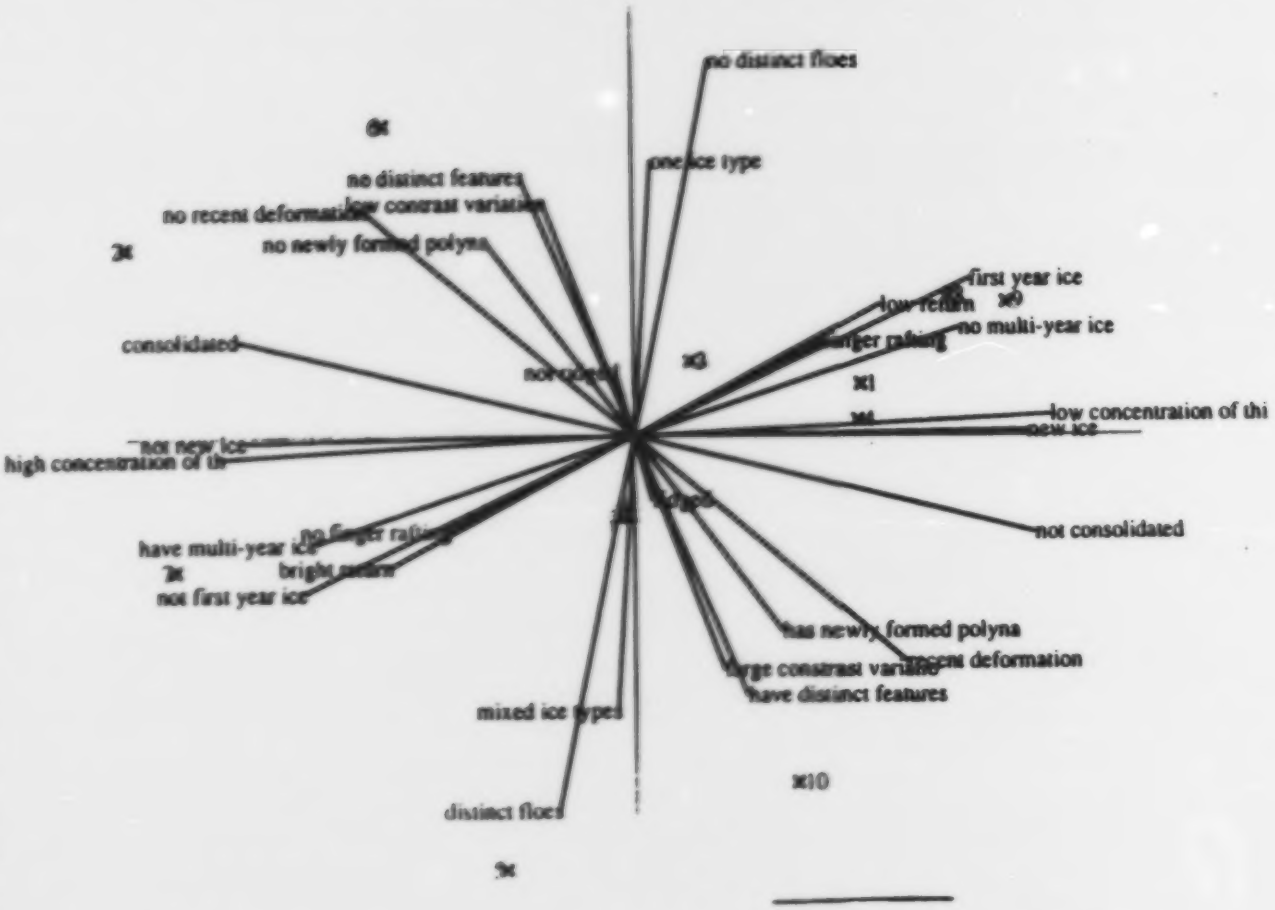
4
10
5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no distinct floes
one ice type
no distinct features
low contrast variation
no recent deformation
no newly formed polyna
first year ice
low return
no multi-year ice
consolidated
not consolidated
low concentration of thi
new ice
not new ice
high concentration of thi
have multi-year ice
bright surface
not first year ice
not consolidated
has newly formed polyna
large constrast variatio
recent deformation
have distinct features
mixed ice types
distinct floes

FOCUS: eric2.ks0
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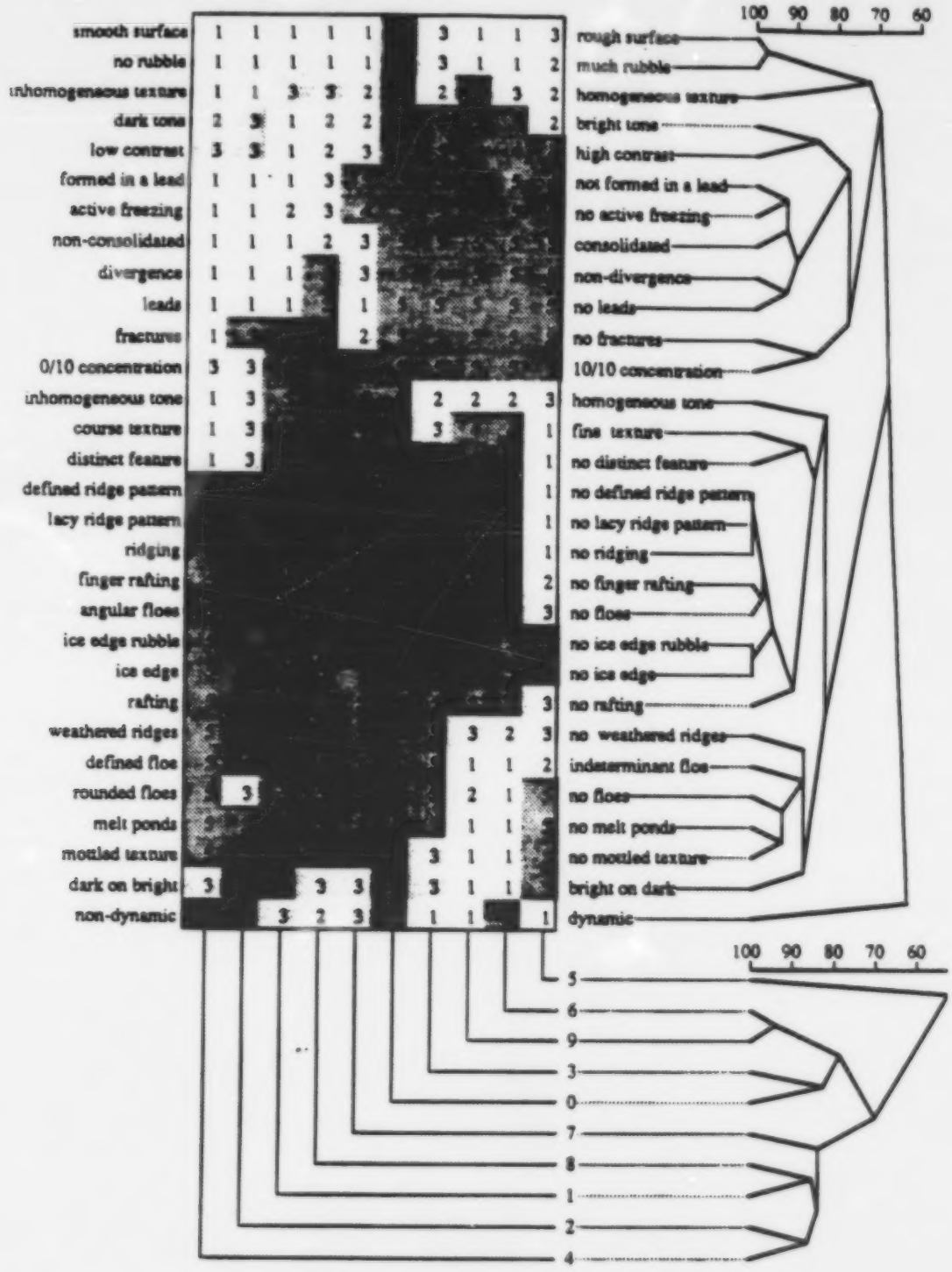

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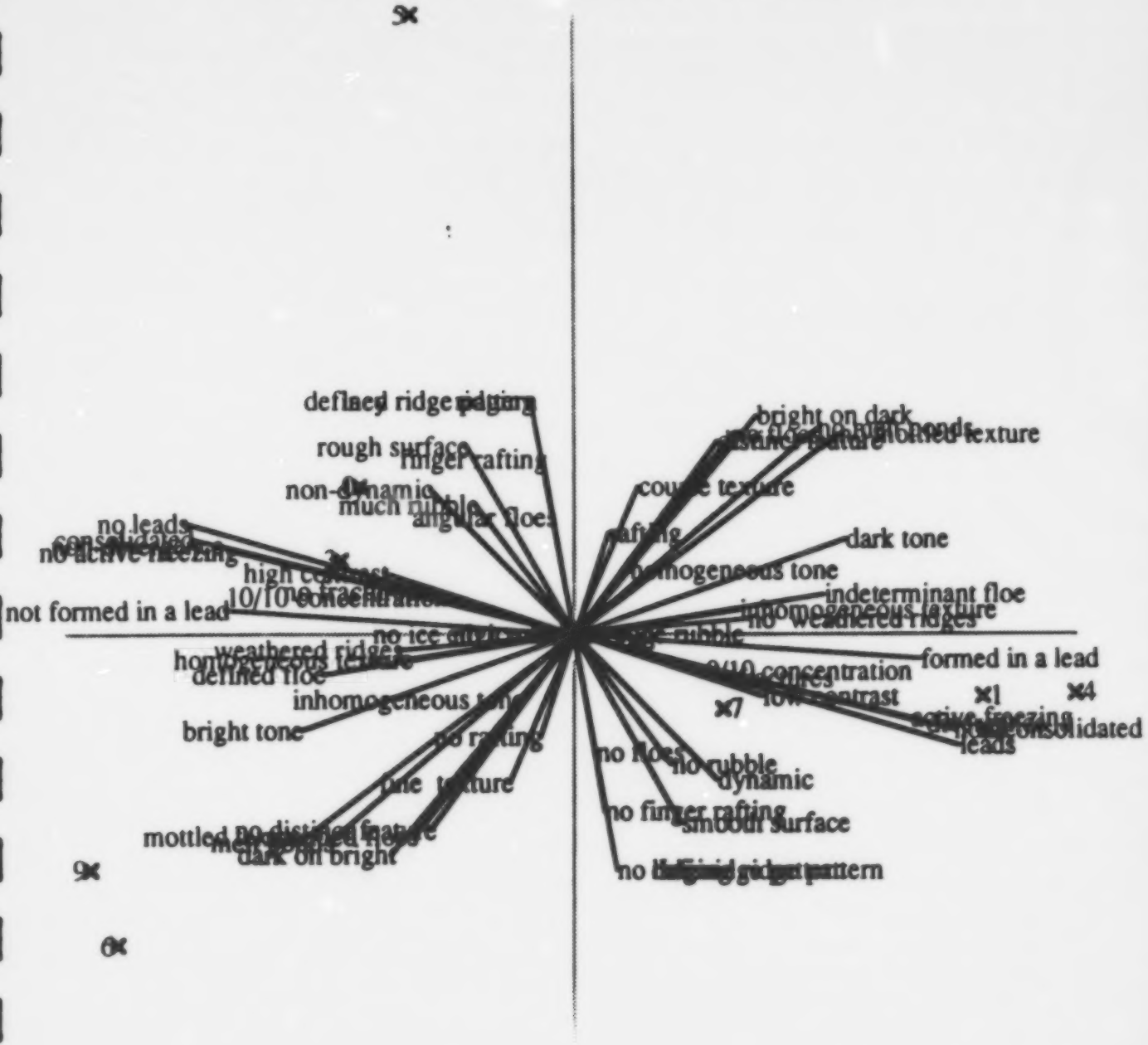

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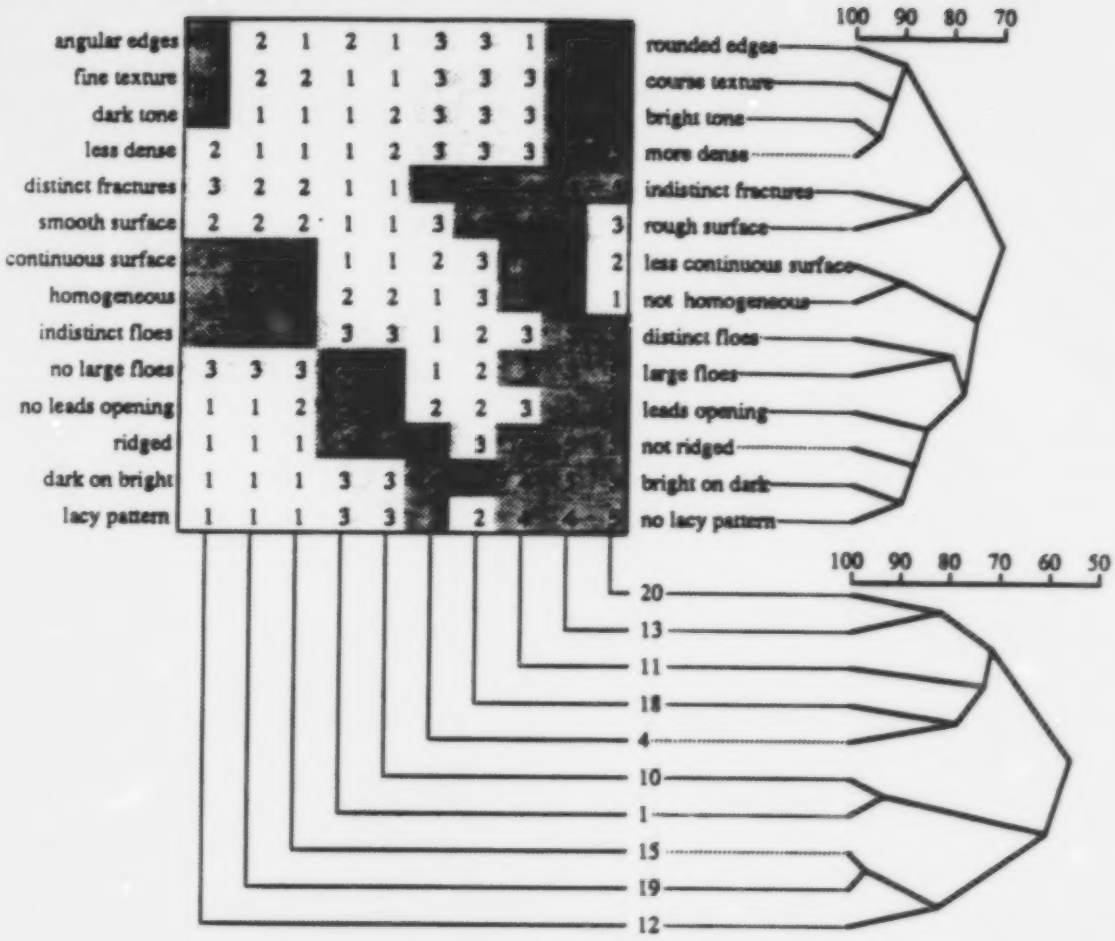
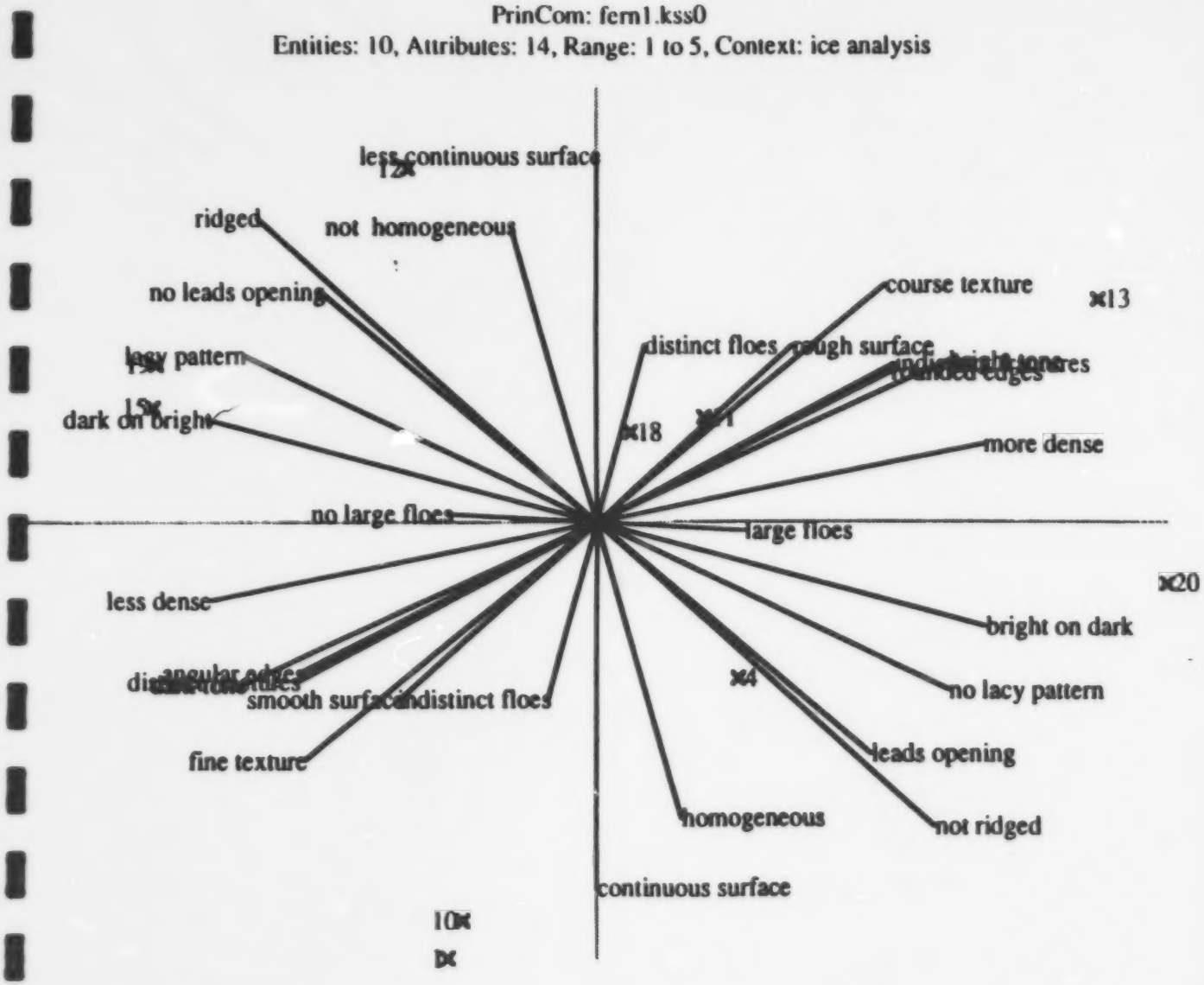
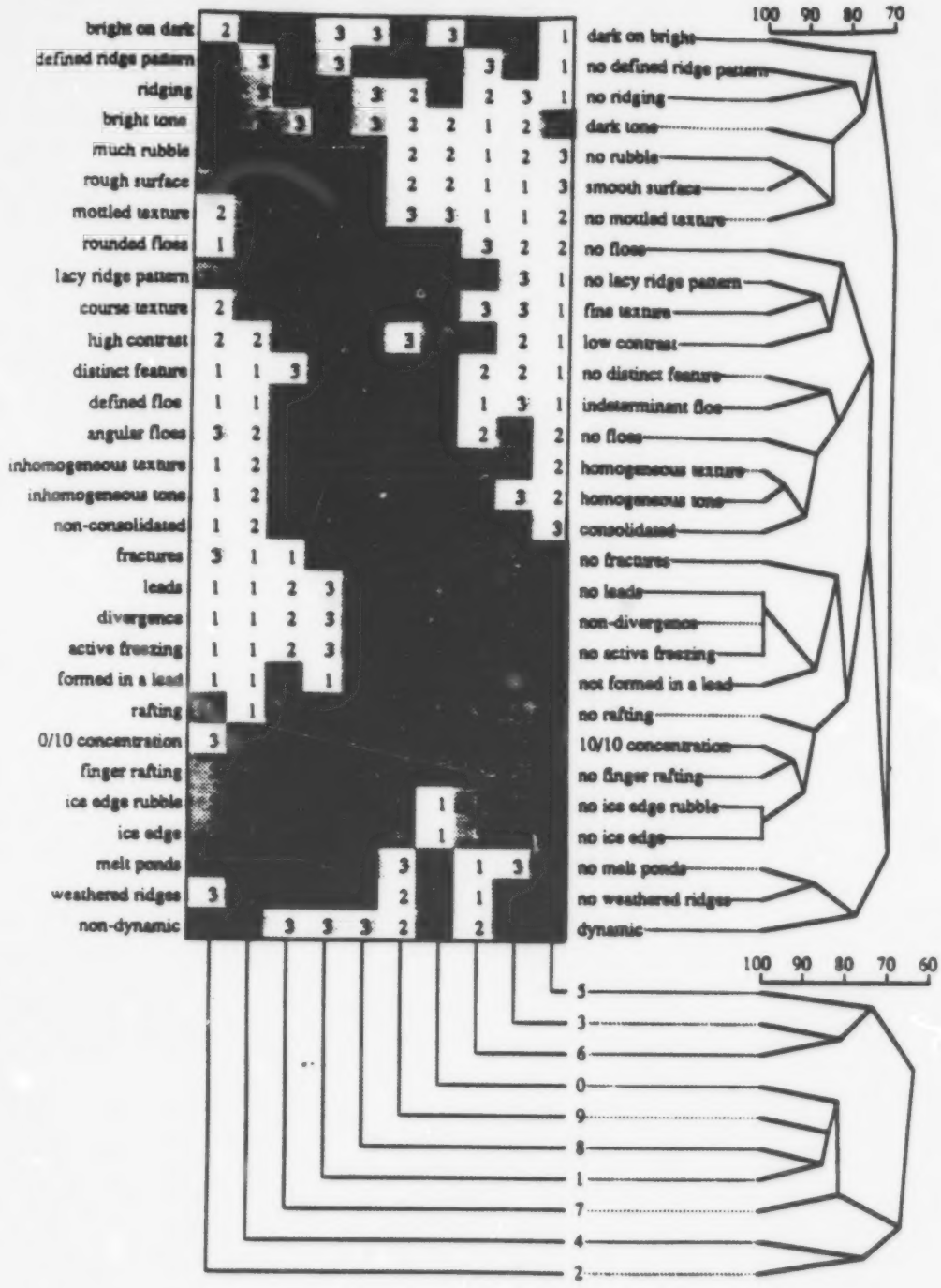
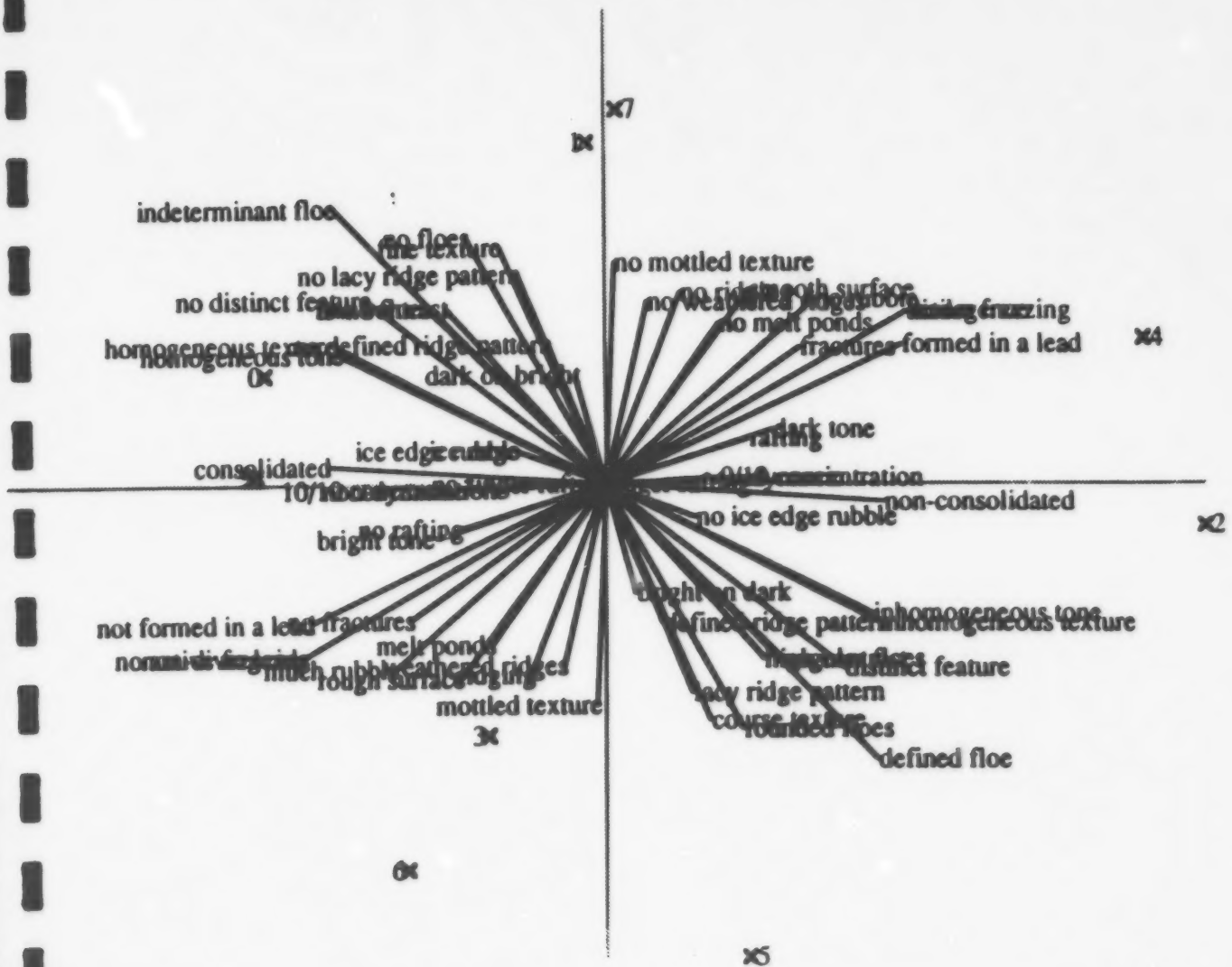


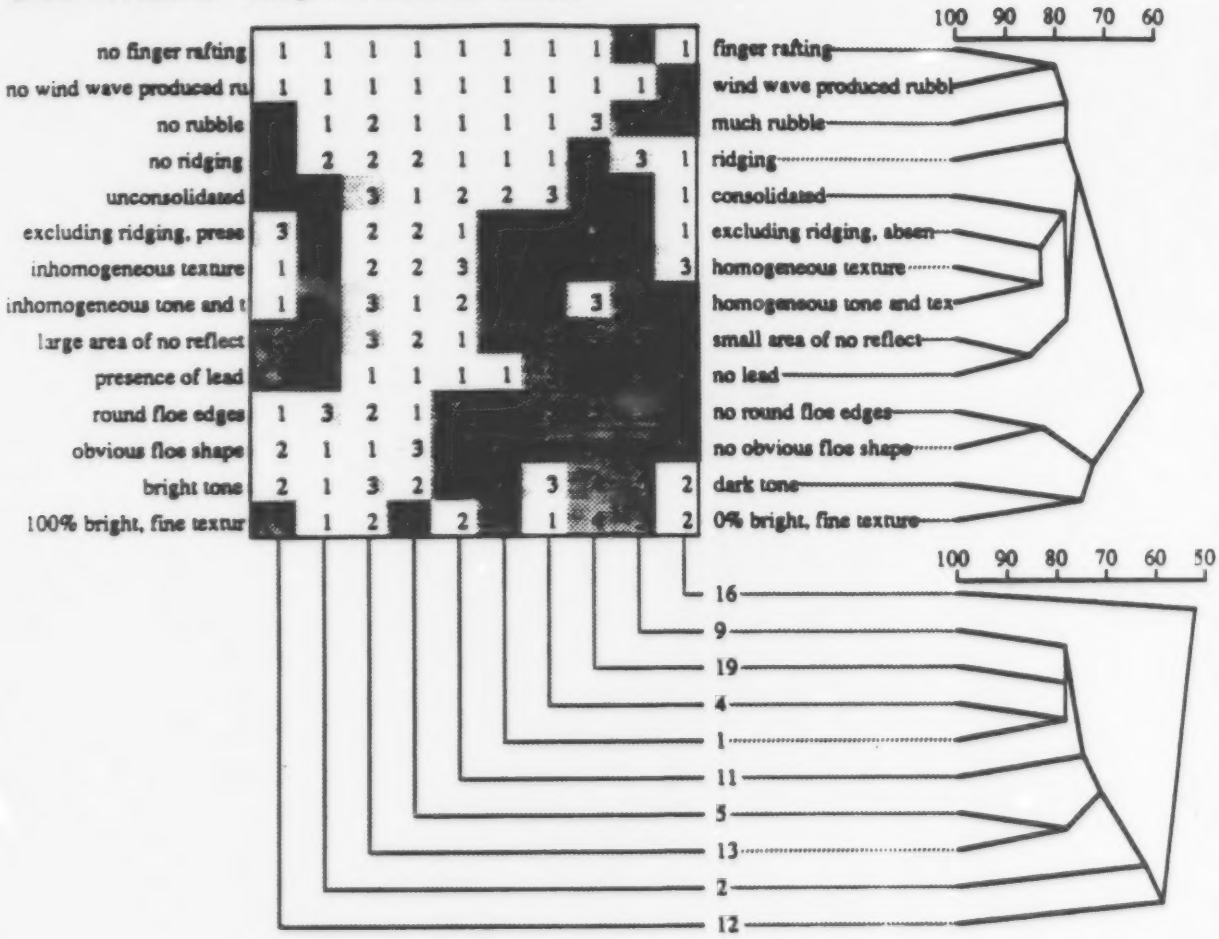

PrinCom: fern1.kss0
Entities: 10, Attributes: 14, Range: 1 to 5, Context: ice analysis
less continuous surface
ridged
not homogeneous
no leads opening
course texture
x13
distinct floes
rough surface
lacy pattern
dark on bright
x18
more dense
no large floes
large floes
x20
less dense
bright on dark
smooth surface
indistinct floes
x4
no lacy pattern
fine texture
leads opening
homogeneous
not ridged
continuous surface
10

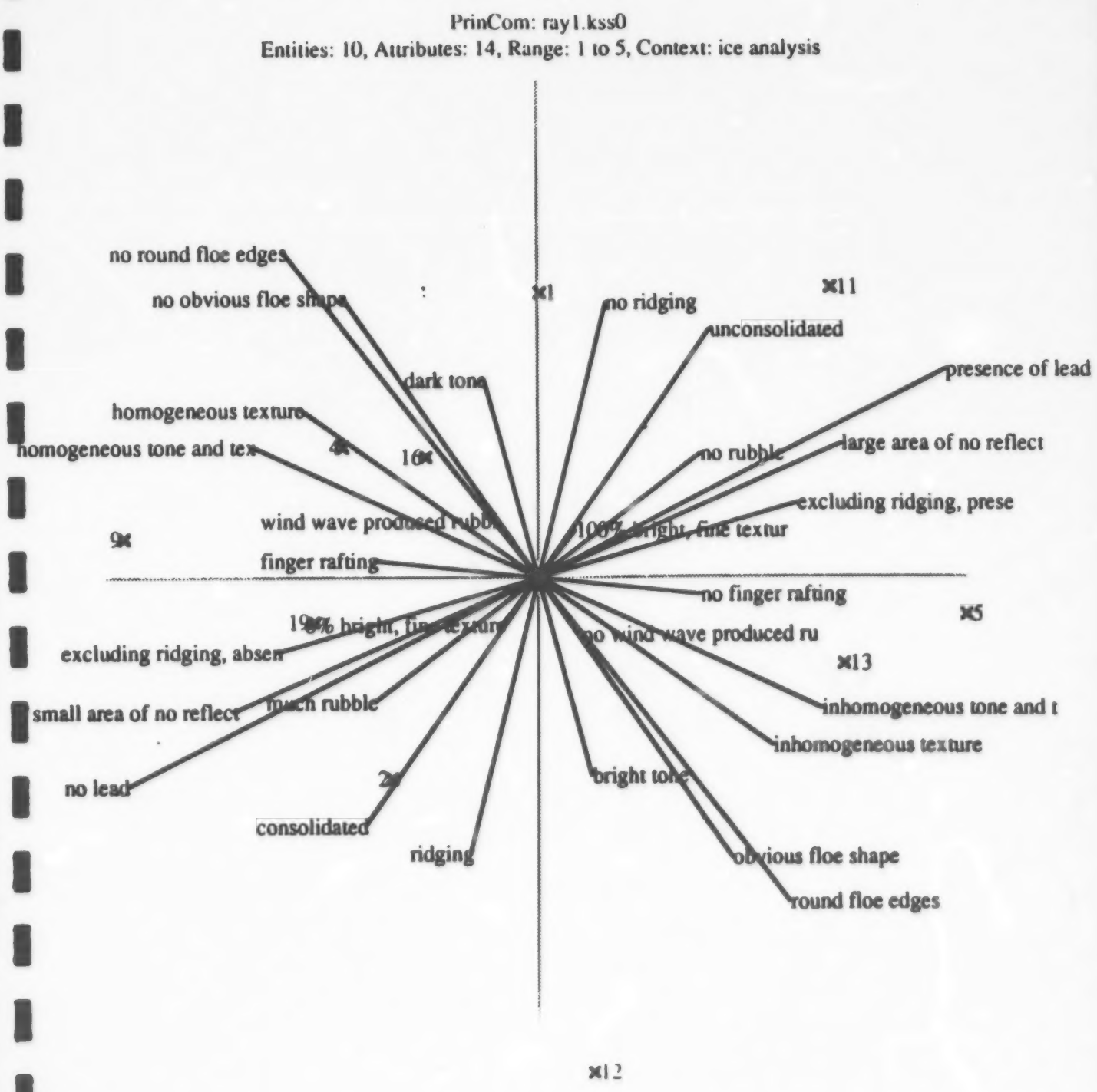

FOCUS: fem2.kss0
Entities: 10, Attributes: 30, Range: 1 to 5, Context: ice-2
bright on dark
defined ridge pattern
ridging
bright tone
much rubble
rough surface
mottled texture
rounded floes
lacy ridge pattern
course texture
high contrast
distinct feature
defined floe
angular floes
inhomogeneous texture
inhomogeneous tone
non-consolidated
fractures
leads
divergence
active freezing
formed in a lead
rafting
0/10 concentration
finger rafting
ice edge rubble
ice edge
melt ponds
weathered ridges
non-dynamic
dark on bright
no defined ridge pattern
no ridging
dark tone
no rubble
smooth surface
no mottled texture
no floes
no lacy ridge pattern
fine texture
low contrast
no distinct feature
indeterminant floe
no floes
homogeneous texture
homogeneous tone
consolidated
no fractures
no leads
non-divergence
no active freezing
not formed in a lead
no rafting
10/10 concentration
no finger rafting
no ice edge rubble
no ice edge
no melt ponds
no weathered ridges
dynamic
100 90 80 70
100 90 80 70 60
5
3
6
0
9
8
1
7
4
2

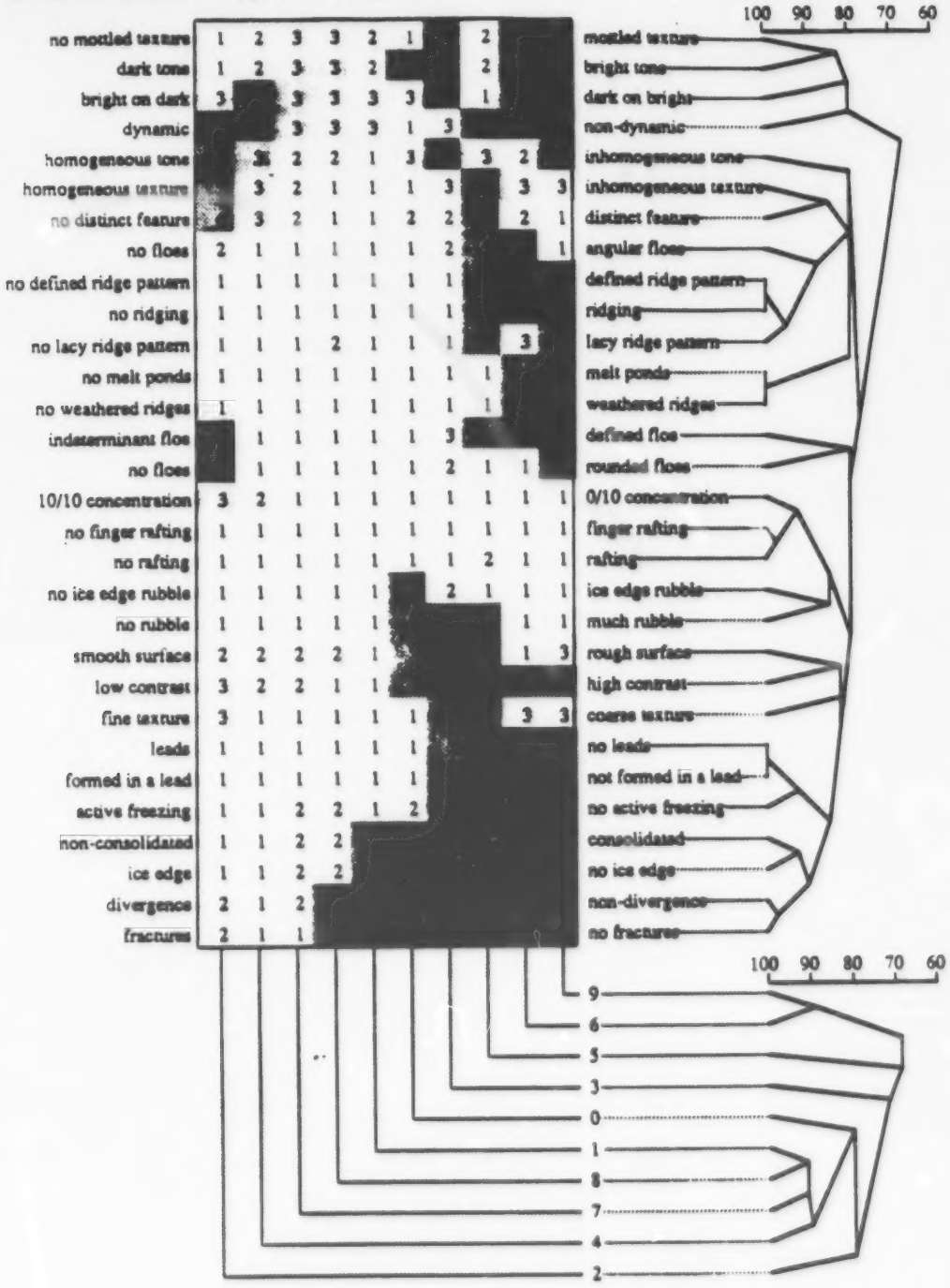
PrinCom: fern2.kss0
Entities: 10, Attributes: 30, Range: 1 to 5, Context: ice-2



FOCUS: ray1.kss0
Entities: 10, Attributes: 14, Range: 1 to 5, Context: ice analysis




PrinCom: ray1.kss0
Entities: 10, Attributes: 14, Range: 1 to 5, Context: ice analysis
no round floe edges
no obvious floe shape
dark tone
homogeneous texture
homogeneous tone and tex
wind wave produced rubb
finger rafting
excluding ridging, absen
small area of no reflect
much rubble
no lead
consolidated
ridging
no ridging
unconsolidated
presence of lead
no rubble
large area of no reflect
excluding ridging, prese
no finger rafting
no wind wave produced ru
inhomogeneous tone and t
inhomogeneous texture
bright tone
obvious floe shape
round floe edges
×1
×11
×5
×13
×12


FOCUS: ray2.kss0
Entities: 10, Attributes: 30, Range: 1 to 5, Constant ice-2
100 90 80 70 60
no mottled texture
dark tone
bright on dark
dynamic
homogeneous tone
homogeneous texture
no distinct feature
no floes
no defined ridge pattern
no ridging
no lacy ridge pattern
no melt ponds
no weathered ridges
indeterminant floe
no floes
10/10 concentration
no finger rafting
no rafting
no ice edge rubble
no rubble
smooth surface
low contrast
fine texture
leads
formed in a lead
active freezing
non-consolidated
ice edge
divergence
fractures
mottled texture
bright tone
dark on bright
non-dynamic
inhomogeneous tone
inhomogeneous texture
distinct feature
angular floes
defined ridge pattern
ridging
lacy ridge pattern
melt ponds
weathered ridges
defined floe
rounded floes
0/10 concentration
finger rafting
rafting
ice edge rubble
much rubble
rough surface
high contrast
coarse texture
no leads
not formed in a lead
no active freezing
consolidated
no ice edge
non-divergence
no fractures
100 90 80 70 60
9
6
5
3
0
1
8
7
4
2

SOCIO - EXCHANGE ANALYSIS

```
Exchange Analysis of 5 Grids

Grid   Ent  Att
* G1    10   30   ray2*
* G2    10   30   fern2*
* G3    10   30   eric2*
* G4    10   30   ed2*
* G5    10   30   clay2*
        10   30   Common Entities & Common Attributes

G1:G2  20.0% over 80.0 (ray2* entity-consensus-with fern2*)
   1:   10.0% ≥ 91.7    E1: 1
   2:   20.0% ≥ 85.8    E7: 7
   3:   30.0% ≥ 84.2    E5: 5
   4:   40.0% ≥ 83.3    E6: 6
   5:              82.5  E2: 2
   6:   60.0% ≥ 82.5    E3: 3
   7:   70.0% ≥ 79.2    E8: 8
   8:   80.0% ≥ 78.3   E10: 0
   9:              72.5  E4: 4
  10:  100.0% ≥ 72.5    E9: 9

G1:G3  26.7% over 80.0 (10 entity-consensus-with eric2*)
   1:   10.0% ≥ 87.5    E1: 1
   2:   20.0% ≥ 86.7    E5: 5
   3:   30.0% ≥ 85.8    E9: 9
   4:              83.3  E3: 3
   5:   50.0% ≥ 83.3    E8: 8
   6:   60.0% ≥ 82.5    E7: 7
   7:   70.0% ≥ 81.7    E4: 4
   8:   80.0% ≥ 80.8   E10: 0
   9:   90.0% ≥ 79.2    E6: 6
  10:  100.0% ≥ 77.5    E2: 2

G1:G4  10.0% over 80.0 (10 entity-consensus-with ed2*)
   1:   10.0% ≥ 87.5    E3: 3
   2:   20.0% ≥ 85.0    E1: 1
   3:   30.0% ≥ 84.2    E4: 4
   4:              79.2  E7: 7
   5:   50.0% ≥ 79.2    E9: 9
   6:   60.0% ≥ 77.5    E8: 8
   7:   70.0% ≥ 76.7   E10: 0
   8:   80.0% ≥ 75.0    E5: 5
   9:   90.0% ≥ 74.2    E2: 2
  10:  100.0% ≥ 71.7    E6: 6

G1:G5  20.0% over 80.0 (10 entity-consensus-with clay2*)
   1:   10.0% ≥ 87.5    E8: 8
   2:   20.0% ≥ 86.7    E1: 1
   3:   30.0% ≥ 85.8    E3: 3
   4:   40.0% ≥ 84.2    E4: 4
   5:              81.7  E2: 2
   6:   60.0% ≥ 81.7    E6: 6
   7:   70.0% ≥ 79.2   E10: 0
   8:   80.0% ≥ 78.3    E5: 5
   9:   90.0% ≥ 77.5    E7: 7
```

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 10: 100.0% ≥ 76.7   E9: 9

G2:G3 16.7% over 80.0 (fern2* entity-consensus-with eric2*)
  1:           84.2   E1: 1
  2:  20.0% ≥ 84.2   E8: 8
  3:  30.0% ≥ 83.3   E7: 7
  4:  40.0% ≥ 82.5  E10: 0
  5:  50.0% ≥ 80.8   E5: 5
  6:  60.0% ≥ 78.3   E2: 2
  7:  70.0% ≥ 75.8   E4: 4
  8:  80.0% ≥ 75.0   E9: 9
  9:           72.5   E3: 3
 10: 100.0% ≥ 72.5   E6: 6

G2:G4 13.3% over 80.0 (10 entity-consensus-with ed2*)
  1:  10.0% ≥ 90.0   E8: 8
  2:           85.0   E1: 1
  3:  30.0% ≥ 85.0  E10: 0
  4:  40.0% ≥ 81.7   E7: 7
  5:  50.0% ≥ 76.7   E6: 6
  6:           75.0   E4: 4
  7:  70.0% ≥ 75.0   E9: 9
  8:  80.0% ≥ 74.2   E5: 5
  9:           73.3   E2: 2
 10: 100.0% ≥ 73.3   E3: 3

G2:G5 13.3% over 80.0 (10 entity-consensus-with clay2*)
  1:           83.3   E1: 1
  2:  20.0% ≥ 83.3   E6: 6
  3:  30.0% ≥ 82.5  E10: 0
  4:  40.0% ≥ 80.8   E2: 2
  5:           78.3   E3: 3
  6:  60.0% ≥ 78.3   E7: 7
  7:  70.0% ≥ 77.5   E9: 9
  8:  80.0% ≥ 76.7   E8: 8
  9:  90.0% ≥ 75.8   E5: 5
 10: 100.0% ≥ 75.0   E4: 4

G3:G4 30.0% over 80.0 (eric2* entity-consensus-with ed2*)
  1:  10.0% ≥ 89.2   E8: 8
  2:           87.5   E3: 3
  3:  30.0% ≥ 87.5   E4: 4
  4:           85.0   E2: 2
  5:  50.0% ≥ 85.0   E9: 9
  6:  60.0% ≥ 84.2  E10: 0
  7:  70.0% ≥ 83.3   E7: 7
  8:  80.0% ≥ 80.8   E6: 6
  9:  90.0% ≥ 80.0   E5: 5
 10: 100.0% ≥ 79.2   E1: 1

G3:G5 23.3% over 80.0 (10 entity-consensus-with clay2*)
  1:           90.8   E1: 1
  2:  20.0% ≥ 90.8   E4: 4
  3:           87.5   E2: 2
  4:  40.0% ≥ 87.5   E8: 8
  5:  50.0% ≥ 85.0   E7: 7
  6:  60.0% ≥ 83.3   E5: 5
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  7:  70.0% ≥ 80.8   E3: 3
  8:  80.0% ≥ 78.3  E10: 0
  9:  90.0% ≥ 77.5   E9: 9
 10: 100.0% ≥ 72.5   E6: 6

G4:G5 23.3% over 80.0 (ed2* entity-consensus-with clay2*)
  1:  10.0% ≥ 88.3   E5: 5
  2:  20.0% ≥ 86.7   E4: 4
  3:  30.0% ≥ 85.0   E3: 3
  4:  40.0% ≥ 81.7   E7: 7
  5:            80.8   E9: 9
  6:  60.0% ≥ 80.8  E10: 0
  7:  70.0% ≥ 80.0   E1: 1
  8:  80.0% ≥ 79.2   E2: 2
  9:  90.0% ≥ 78.3   E8: 8
 10: 100.0% ≥ 73.3   E6: 6

Entity Links between Grids
 G3:3G4  90.0% over  80.0 (eric2* entity-consensus-with ed2*)
 G1:3G3  80.0% over  80.0 (ray2* entity-consensus-with eric2*)
 G3:3G5  70.0% over  80.0 (eric2* entity-consensus-with clay2*)
 G4:3G5  70.0% over  80.0 (ed2* entity-consensus-with clay2*)
 G1:3G2  60.0% over  80.0 (ray2* entity-consensus-with fern2*)
 G1:3G5  60.0% over  80.0 (ray2* entity-consensus-with clay2*)
 G2:3G3  50.0% over  80.0 (fern2* entity-consensus-with eric2*)
 G2:3G4  40.0% over  80.0 (fern2* entity-consensus-with ed2*)
 G2:3G5  40.0% over  80.0 (fern2* entity-consensus-with clay2*)
 G1:3G4  30.0% over  80.0 (ray2* entity-consensus-with ed2*)

G1:G2 53.3% over 80.0 (ray2* attribute-consensus-with fern2*)
  1:          100.0  A26: no finger rafting - finger rafting
  2:   6.7% ≥100.0  A28: 0/10 concentration - 10/10 concentration
  3:  10.0% ≥ 97.5   A6: no ice edge rubble - ice edge rubble
  4:            92.5   A2: non-divergence - divergence
  5:            92.5   A7: dark tone - bright tone
  6:  20.0% ≥ 92.5  A22: no fractures - fractures
  7:  23.3% ≥ 90.0  A24: no melt ponds - melt ponds
  8:            87.5  A25: no rafting - rafting
  9:  30.0% ≥ 87.5  A30: no weathered ridges - weathered ridges
 10:            85.0   A8: no floes - angular floes
 11:  36.7% ≥ 85.0  A18: dark on bright - bright on dark
 12:            82.5   A4: rough surface - smooth surface
 13:            82.5   A9: coarse texture - fine texture
 14:  46.7% ≥ 82.5  A27: inhomogeneous texture - homogeneous texture
 15:            80.0  A14: no active freezing - active freezing
 16:  53.3% ≥ 80.0  A19: no ridging - ridging
 17:            77.5   A1: no distinct feature - distinct feature
 18:            77.5   A3: no lacy ridge pattern - lacy ridge pattern
 19:            77.5  A11: inhomogeneous tone - homogeneous tone
 20:            77.5  A13: indeterminant floes - defined floes
 21:  70.0% ≥ 77.5  A20: non-consolidated - consolidated
 22:            75.0  A12: no rubble - much rubble
 23:  76.7% ≥ 75.0  A21: no defined ridge pattern - defined ridge pattern
 24:            72.5  A15: no mottled texture - mottled texture
 25:            72.5  A17: no leads - leads
 26:  86.7% ≥ 72.5  A23: no floes - rounded floes
 27:            70.0   A5: low contrast - high contrast
```

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28:          70.0  A16: not formed in a lead - formed in a lead
29:  96.7% ≥ 70.0  A29: non-dynamic - dynamic
30: 100.0% ≥ 55.0  A10: no ice edge - ice edge

G1:G3 73.3% over 80.0 (30 attribute-consensus-with eric2°)
  1:   3.3% ≥100.0  A24: no melt ponds - melt ponds
  2:   6.7% ≥ 95.0  A28: 0/10 concentration - 10/10 concentration
  3:          92.5  A25: no rafting - rafting
  4:  13.3% ≥ 92.5  A26: no finger rafting - finger rafting
  5:          90.0   A5: low contrast - high contrast
  6:          90.0  A12: no rubble - much rubble
  7:  23.3% ≥ 90.0  A22: no fractures - fractures
  8:          87.5   A6: no ice edge rubble - ice edge rubble
  9:          87.5  A13: indeterminant floes - defined floes
 10:  33.3% ≥ 87.5  A30: no weathered ridges - weathered ridges
 11:          85.0   A3: no lacy ridge pattern - lacy ridge pattern
 12:          85.0   A7: dark tone - bright tone
 13:          85.0  A19: no ridging - ridging
 14:          85.0  A20: non-consolidated - consolidated
 15:  50.0% ≥ 85.0  A21: no defined ridge pattern - defined ridge pattern
 16:          82.5   A1: no distinct feature - distinct feature
 17:          82.5   A2: non-divergence - divergence
 18:          82.5   A8: no floes - angular floes
 19:  63.3% ≥ 82.5  A14: no active freezing - active freezing
 20:          80.0  A17: no leads - leads
 21:          80.0  A18: dark on bright - bright on dark
 22:  73.3% ≥ 80.0  A23: no floes - rounded floes
 23:          77.5   A4: rough surface - smooth surface
 24:  80.0% ≥ 77.5  A11: inhomogeneous tone - homogeneous tone
 25:          75.0   A9: coarse texture - fine texture
 26:  86.7% ≥ 75.0  A15: no mottled texture - mottled texture
 27:          72.5  A16: not formed in a lead - formed in a lead
 28:  93.3% ≥ 72.5  A27: inhomogeneous texture - homogeneous texture
 29:  96.7% ≥ 65.0  A10: no ice edge - ice edge
 30: 100.0% ≥ 62.5  A29: non-dynamic - dynamic

G1:G4 56.7% over 80.0 (30 attribute-consensus-with ed2°)
  1:   3.3% ≥100.0  A30: no weathered ridges - weathered ridges
  2:          97.5  A24: no melt ponds - melt ponds
  3:  10.0% ≥ 97.5  A28: 0/10 concentration - 10/10 concentration
  4:          92.5   A7: dark tone - bright tone
  5:          92.5  A22: no fractures - fractures
  6:  20.0% ≥ 92.5  A25: no rafting - rafting
  7:          90.0  A12: no rubble - much rubble
  8:  26.7% ≥ 90.0  A26: no finger rafting - finger rafting
  9:          85.0   A3: no lacy ridge pattern - lacy ridge pattern
 10:          85.0   A8: no floes - angular floes
 11:          85.0  A19: no ridging - ridging
 12:  46.0% ≥ 85.0  A21: no defined ridge pattern - defined ridge pattern
 13:          82.5   A2: non-divergence - divergence
 14:          82.5   A5: low contrast - high contrast
 15:          82.5   A6: no ice edge rubble - ice edge rubble
 16:  53.3% ≥ 82.5  A13: indeterminant floes - defined floes
 17:  56.7% ≥ 80.0  A20: non-consolidated - consolidated
 18:          77.5  A11: inhomogeneous tone - homogeneous tone
 19:  63.3% ≥ 77.5  A27: inhomogeneous texture - homogeneous texture
 20:  66.7% ≥ 75.0   A4: rough surface - smooth surface
```

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 21:            72.5   A9: coarse texture - fine texture
 22:            72.5   A16: not formed in a lead - formed in a lead
 23:   76.7% ≥ 72.5   A23: no floes - rounded floes
 24:   80.0% ≥ 70.0   A14: no active freezing - active freezing
 25:            65.0    A1: no distinct feature - distinct feature
 26:   86.7% ≥ 65.0   A10: no ice edge - ice edge
 27:            62.5   A15: no mottled texture - mottled texture
 28:   93.3% ≥ 62.5   A18: dark on bright - bright on dark
 29:   96.7% ≥ 55.0   A17: no leads - leads
 30:  100.0% ≥ 40.0   A29: non-dynamic - dynamic

21:G5  63.3% over 80.0 (30 attribute-consensus-with clay2*)
  1:    3.3% ≥100.0   A30: no weathered ridges - weathered ridges
  2:            97.5    A6: no ice edge rubble - ice edge rubble
  3:   10.0% ≥ 97.5   A24: no melt ponds - melt ponds
  4:            95.0   A14: no active freezing - active freezing
  5:            95.0   A21: no defined ridge pattern - defined ridge pattern
  6:   20.0% ≥ 95.0   A25: no rafting - rafting
  7:            92.5   A19: no ridging - ridging
  8:   26.7% ≥ 92.5   A26: no finger rafting - finger rafting
  9:   30.0% ≥ 90.0   A22: no fractures - fractures
 10:            87.5    A8: no floes - angular floes
 11:   36.7% ≥ 87.5   A13: indeterminant floes - defined floes
 12:            85.0    A2: non-divergence - divergence
 13:            85.0    A3: no lacy ridge pattern - lacy ridge pattern
 14:   46.7% ≥ 85.0    A7: dark tone - bright tone
 15:   50.0% ≥ 82.5    A4: rough surface - smooth surface
 16:            80.0   A12: no rubble - much rubble
 17:            80.0   A16: not formed in a lead - formed in a lead
 18:            80.0   A17: no leads - leads
 19:   63.3% ≥ 80.0   A18: dark on bright - bright on dark
 20:   66.7% ≥ 77.5   A23: no floes - rounded floes
 21:            75.0    A1: no distinct feature - distinct feature
 22:   73.3% ≥ 75.0   A15: no mottled texture - mottled texture
 23:            70.0   A11: inhomogeneous tone - homogeneous tone
 24:            70.0   A20: non-consolidated - consolidated
 25:            70.0   A28: 0/10 concentration - 10/10 concentration
 26:   86.7% ≥ 70.0   A29: non-dynamic - dynamic
 27:            67.5   A10: no ice edge - ice edge
 28:   93.3% ≥ 67.5   A27: inhomogeneous texture - homogeneous texture
 29:   96.7% ≥ 65.0    A9: coarse texture - fine texture
 30:  100.0% ≥ 62.5    A5: low contrast - high contrast

22:G3  50.0% over 80.0 (fern2* attribute-consensus-with eric2*)
  1:    3.3% ≥ 95.0   A28: 0/10 concentration - 10/10 concentration
  2:            92.5   A16: not formed in a lead - formed in a lead
  3:            92.5   A17: no leads - leads
  4:   13.3% ≥ 92.5   A26: no finger rafting - finger rafting
  5:            90.0    A2: non-divergence - divergence
  6:            90.0    A6: no ice edge rubble - ice edge rubble
  7:            90.0   A10: no ice edge - ice edge
  8:   26.7% ≥ 90.0   A24: no melt ponds - melt ponds
  9:            87.5    A3: no lacy ridge pattern - lacy ridge pattern
 10:            87.5   A14: no active freezing - active freezing
 11:   36.7% ≥ 87.5   A22: no fractures - fractures
 12:   40.0% ≥ 85.0   A30: no weathered ridges - weathered ridges
 13:   43.3% ≥ 82.5    A9: coarse texture - fine texture
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 14:          80.0  A21: no defined ridge pattern - defined ridge pattern
 15:  50.0% ≥ 80.0  A25: no rafting - rafting
 16:          77.5   A7: dark tone - bright tone
 17:  56.7% ≥ 77.5   A8: no floes - angular floes
 18:  60.0% ≥ 75.0  A11: inhomogeneous tone - homogeneous tone
 19:          72.5  A20: non-consolidated - consolidated
 20:  66.7% ≥ 72.5  A29: non-dynamic - dynamic
 21:          70.0   A1: no distinct feature - distinct feature
 22:          70.0  A12: no rubble - much rubble
 23:          70.0  A18: dark on bright - bright on dark
 24:  80.0% ≥ 70.0  A27: inhomogeneous texture - homogeneous texture
 25:  83.3% ≥ 67.5  A23: no floes - rounded floes
 26:          65.0   A4: rough surface - smooth surface
 27:          65.0   A5: low contrast - high contrast
 28:          65.0  A13: indeterminant floes - defined floes
 29:  96.7% ≥ 65.0  A19: no ridging - ridging
 30: 100.0% ≥ 62.5  A15: no mottled texture - mottled texture

G2:G4 63.3% over 80.0 (30 attribute-consensus-with ed2*)
  1:   3.3% ≥ 97.5  A28: 0/10 concentration - 10/10 concentration
  2:          90.0   A7: dark tone - bright tone
  3:          90.0  A10: no ice edge - ice edge
  4:          90.0  A14: no active freezing - active freezing
  5:          90.0  A22: no fractures - fractures
  6:  20.0% ≥ 90.0  A26: no finger rafting - finger rafting
  7:          87.5   A3: no lacy ridge pattern - lacy ridge pattern
  8:          87.5   A4: rough surface - smooth surface
  9:          87.5  A16: not formed in a lead - formed in a lead
 10:          87.5  A20: non-consolidated - consolidated
 11:          87.5  A24: no melt ponds - melt ponds
 12:  40.0% ≥ 87.5  A30: no weathered ridges - weathered ridges
 13:          85.0   A2: non-divergence - divergence
 14:  46.7% ≥ 85.0   A6: no ice edge rubble - ice edge rubble
 15:  50.0% ≥ 82.5  A17: no leads - leads
 16:          80.0   A8: no floes - angular floes
 17:          80.0  A21: no defined ridge pattern - defined ridge pattern
 18:          80.0  A25: no rafting - rafting
 19:  63.3% ≥ 80.0  A27: inhomogeneous texture - homogeneous texture
 20:          75.0  A11: inhomogeneous tone - homogeneous tone
 21:  70.0% ≥ 75.0  A23: no floes - rounded floes
 22:  73.3% ≥ 72.5   A5: low contrast - high contrast
 23:          70.0  A12: no rubble - much rubble
 24:  80.0% ≥ 70.0  A13: indeterminant floes - defined floes
 25:          65.0   A9: coarse texture - fine texture
 26:  86.7% ≥ 65.0  A19: no ridging - ridging
 27:  90.0% ≥ 62.5  A18: dark on bright - bright on dark
 28:  93.3% ≥ 60.0  A15: no mottled texture - mottled texture
 29:  96.7% ≥ 57.5   A1: no distinct feature - distinct feature
 30: 100.0% ≥ 50.0  A29: non-dynamic - dynamic

G2:G5 53.3% over 80.0 (30 attribute-consensus-with clay2*)
  1:   3.3% ≥100.0   A6: no ice edge rubble - ice edge rubble
  2:   6.7% ≥ 95.0   A4: rough surface - smooth surface
  3:          92.5  A24: no melt ponds - melt ponds
  4:  13.3% ≥ 92.5  A26: no finger rafting - finger rafting
  5:          90.0  A13: indeterminant floes - defined floes
  6:          90.0  A16: not formed in a lead - formed in a lead
```

```
  7:  23.3% ≥ 90.0  A23: no floes - rounded floes
  8:            87.5   A2: non-divergence - divergence
  9:            87.5   A3: no lacy ridge pattern - lacy ridge pattern
 10:            87.5  A10: no ice edge - ice edge
 11:            87.5  A22: no fractures - fractures
 12:  40.0% ≥ 87.5  A30: no weathered ridges - weathered ridges
 13:            82.5   A8: no floes - angular floes
 14:  46.7% ≥ 82.5  A25: no rafting - rafting
 15:            80.0  A18: dark on bright - bright on dark
 16:  53.3% ≥ 80.0  A21: no defined ridge pattern - defined ridge pattern
 17:            77.5   A5: low contrast - high contrast
 18:            77.5   A7: dark tone - bright tone
 19:            77.5  A17: no leads - leads
 20:  66.7% ≥ 77.5  A19: no ridging - ridging
 21:  70.0% ≥ 75.0  A14: no active freezing - active freezing
 22:  73.3% ≥ 72.5  A11: inhomogeneous tone - homogeneous tone
 23:            70.0  A28: 0/10 concentration - 10/10 concentration
 24:  80.0% ≥ 70.0  A29: non-dynamic - dynamic
 25:  83.3% ≥ 67.5  A15: no mottled texture - mottled texture
 26:  86.7% ≥ 65.0  A27: inhomogeneous texture - homogeneous texture
 27:  90.0% ≥ 60.0  A12: no rubble - much rubble
 28:            57.5   A1: no distinct feature - distinct feature
 29:            57.5   A9: coarse texture - fine texture
 30: 100.0% ≥ 57.5  A20: non-consolidated - consolidated

G3:G4 73.3% over 80.0 (eric2* attribute-consensus-with ed2*)
  1:           100.0   A3: no lacy ridge pattern - lacy ridge pattern
  2:           100.0  A10: no ice edge - ice edge
  3:           100.0  A19: no ridging - ridging
  4:  13.3% ≥100.0  A21: no defined ridge pattern - defined ridge pattern
  5:            97.5  A22: no fractures - fractures
  6:            97.5  A24: no melt ponds - melt ponds
  7:  23.3% ≥ 97.5  A26: no finger rafting - finger rafting
  8:  26.7% ≥ 95.0  A12: no rubble - much rubble
  9:  30.0% ≥ 92.5  A28: 0/10 concentration - 10/10 concentration
 10:            90.0  A13: indeterminant floes - defined floes
 11:  36.7% ≥ 90.0  A25: no rafting - rafting
 12:            87.5   A5: low contrast - high contrast
 13:            87.5   A8: no floes - angular floes
 14:            87.5  A14: no active freezing - active freezing
 15:            87.5  A15: no mottled texture - mottled texture
 16:  53.3% ≥ 87.5  A30: no weathered ridges - weathered ridges
 17:  56.7% ≥ 85.0  A16: not formed in a lead - formed in a lead
 18:            82.5   A7: dark tone - bright tone
 19:  63.3% ≥ 82.5  A23: no floes - rounded floes
 20:            80.0   A2: non-divergence - divergence
 21:            80.0  A11: inhomogeneous tone - homogeneous tone
 22:  73.3% ≥ 80.0  A20: non-consolidated - consolidated
 23:            77.5   A4: rough surface - smooth surface
 24:  80.0% ≥ 77.5  A29: non-dynamic - dynamic
 25:            75.0   A6: no ice edge rubble - ice edge rubble
 26:  86.7% ≥ 75.0  A17: no leads - leads
 27:  90.0% ≥ 70.0  A27: inhomogeneous texture - homogeneous texture
 28:  93.3% ≥ 57.5   A9: coarse texture - fine texture
 29:            52.5   A1: no distinct feature - distinct feature
 30: 100.0% ≥ 52.5  A18: dark on bright - bright on dark
```

```
G3:G5 70.0% over 80.0 (3D attribute-consensus-with clay2*)
  1:          100.0    A3: no lacy ridge pattern - lacy ridge pattern
  2:   6.7% ≥100.0   A26: no finger rafting - finger rafting
  3:           97.5   A10: no ice edge - ice edge
  4:  13.3% ≥ 97.5   A24: no melt ponds - melt ponds
  5:           95.0    A7: dark tone - bright tone
  6:  20.0% ≥ 95.0   A22: no fractures - fractures
  7:           92.5   A16: not formed in a lead - formed in a lead
  8:  26.7% ≥ 92.5   A25: no rafting - rafting
  9:           90.0    A6: no ice edge rubble - ice edge rubble
 10:           90.0    A8: no floes - angular floes
 11:  36.7% ≥ 90.0   A21: no defined ridge pattern - defined ridge pattern
 12:           87.5    A1: no distinct feature - distinct feature
 13:           87.5    A2: non-divergence - divergence
 14:           87.5   A11: inhomogeneous tone - homogeneous tone
 15:           87.5   A19: no ridging - ridging
 16:  53.3% ≥ 87.5   A30: no weathered ridges - weathered ridges
 17:           85.0   A12: no rubble - much rubble
 18:  60.0% ≥ 85.0   A27: inhomogeneous texture - homogeneous texture
 19:           80.0   A15: no mottled texture - mottled texture
 20:           80.0   A17: no leads - leads
 21:  70.0% ≥ 80.0   A20: non-consolidated - consolidated
 22:           77.5   A14: no active freezing - active freezing
 23:  76.7% ≥ 77.5   A29: non-dynamic - dynamic
 24:           75.0   A13: indeterminant floes - defined floes
 25:  83.3% ≥ 75.0   A28: 0/10 concentration - 10/10 concentration
 26:  86.7% ≥ 70.0   A18: dark on bright - bright on dark
 27:  90.0% ≥ 67.5   A23: no floes - rounded floes
 28:  93.3% ≥ 65.0    A4: rough surface - smooth surface
 29:  96.7% ≥ 57.5    A5: low contrast - high contrast
 30: 100.0% ≥ 50.0    A9: coarse texture - fine texture

G4:G5 60.0% over 80.0 (ed2* attribute-consensus-with clay2*)
  1:          100.0    A3: no lacy ridge pattern - lacy ridge pattern
  2:   6.7% ≥100.0   A30: no weathered ridges - weathered ridges
  3:           97.5   A10: no ice edge - ice edge
  4:           97.5   A22: no fractures - fractures
  5:           97.5   A25: no rafting - rafting
  6:  20.0% ≥ 97.5   A26: no finger rafting - finger rafting
  7:  23.3% ≥ 95.0   A24: no melt ponds - melt ponds
  8:  26.7% ≥ 90.0   A21: no defined ridge pattern - defined ridge pattern
  9:           87.5    A8: no floes - angular floes
 10:           87.5    A9: coarse texture - fine texture
 11:  36.7% ≥ 87.5   A19: no ridging - ridging
 12:  40.0% ≥ 85.0    A6: no ice edge rubble - ice edge rubble
 13:           82.5    A4: rough surface - smooth surface
 14:           82.5    A7: dark tone - bright tone
 15:           82.5   A15: no mottled texture - mottled texture
 16:  53.3% ≥ 82.5   A16: not formed in a lead - formed in a lead
 17:           80.0   A12: no rubble - much rubble
 18:  60.0% ≥ 80.0   A13: indeterminant floes - defined floes
 19:           77.5    A2: non-divergence - divergence
 20:  66.7% ≥ 77.5   A11: inhomogeneous tone - homogeneous tone
 21:  70.0% ≥ 75.0   A17: no leads - leads
 22:  73.3% ≥ 72.5   A28: 0/10 concentration - 10/10 concentration
 23:           70.0   A23: no floes - rounded floes
 24:  80.0% ≥ 70.0   A29: non-dynamic - dynamic
```

```
25:            65.0   A1: no distinct feature - distinct feature
26:            65.0   A5: low contrast - high contrast
27:            65.0  A14: no active freezing - active freezing
28:            65.0  A20: non-consolidated - consolidated
29:  96.7% ≥ 65.0  A27: inhomogeneous texture - homogeneous texture
30: 100.0% ≥ 62.5  A18: dark on bright - bright on dark

Attribute Links between Grids
 G1:3G3   73.3% over  80.0 (ray2* attribute-consensus-with eric2*)
 G3:3G4   73.3% over  80.0 (eric2* attribute-consensus-with ed2*)
 G3:3G5   70.0% over  80.0 (eric2* attribute-consensus-with clay2*)
 G1:3G5   63.3% over  80.0 (ray2* attribute-consensus-with clay2*)
 G2:3G4   63.3% over  80.0 (fern2* attribute-consensus-with ed2*)
 G4:3G5   60.0% over  80.0 (ed2* attribute-consensus-with clay2*)
 G1:3G4   56.7% over  80.0 (ray2* attribute-consensus-with ed2*)
 G1:3G2   53.3% over  80.0 (ray2* attribute-consensus-with fern2*)
 G2:3G5   53.3% over  80.0 (fern2* attribute-consensus-with clay2*)
 G2:3G3   50.0% over  80.0 (fern2* attribute-consensus-with eric2*)
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APPENDIX D

SAR ICE INTERPRETATION GLOSSARY

1. INTRODUCTION

The glossary is divided into 5 major sections which reflect the different hierarchies in the data structure. The five major levels are:

1. Elements
   The basis elements such as tone and texture which are observed at the pixel level. Elements only refer to the image.

2. Features
   The individual physical entities such as ridges which are observed in an ice field and on an image.

3. Patterns
   Describes the patterns or combinations which are developed by the various features. Patterns refer to both physical and image attributes.

4. Classifications
   Describes the different types of sheet ice.

5. Processes
   Ice behavior which is inferred from observing other attributes.

Each level contains a number of members. Under the feature level an example of a feature is a ridge. Each member is described by a standard set of parameters. These parameters are:

1. Interpretation
   Describes how the member is identified on an image.

2. Definition
   Describes the physical character of the member (i.e. what the member would look like if it were ground truth).

* 2. Significance
   Describes what the member indicates about the ice type or condition.

3. Cause
   Describes what processes and forces generate a member.

* 4. Context
   Describes when and where the member is formed.

5. Navigation
   Describes how the member affects vessel navigation.

1.1 Standards

The following interpretations always refer to a positive image. Bright tone indicates high radar return whereas dark tone indicates a lack of radar return.

2. ELEMENTS

Refers to the attributes of a SAR image.

2.1.1 Tone

Interpretation: The tone indicates the magnitude of the radar return. A bright tone indicates high return whereas dark tone denotes lack of return. Tone is measured by individual pixel or for an area of pixels.

Significance: The tone is observed to vary for different ice types.

dark tone -cl

- -can indicate open water since water absorbs the transmitted electromagnetic energy.
- -can indicate very flat smooth first year ice since electromagnetic energy is reflected off surface

grey tone -di

- -common for first-year ice
- -tone quality varies with both the surface roughness and the surface salt content.

bright tone -si

- -common characteristic of multi-year ice due to electromagnetic properties of ice surface
- -common for very young ice (less than 3 days) due to surface salt content

Cause: The return is a function of the type of ice (i.e. electro-magnetic properties) and/or the physical nature (i.e. sharp corners of ice blocks for example) of a feature. Ridges give a bright return due to geometry and multi-year ice gives a bright return due to the electro-magnetic properties of the ice. Open water gives no return since all energy is absorbed.

The tonal quality will vary depending on the transmitted radar energy. Higher transmitter power results in higher return signals.

The tonal quality varies with changes in resolution. With a high resolution radar small targets will give a bright return, whereas with a low resolution radar the bright return would be integrated with potentially lower surrounding returns and reduce the tone.

2.1.1 Homogeneous Tone

Interpretation: Homogeneous tone is consistent and uniform tone from pixel to pixel in any direction. The tone can vary from bright to dark. Inhomogeneous tone is a variation in the tone in one or all directions. Scale of measurement is an important factor.

Significance: Indicates homogeneous ice over an area.

Cause: Homogeneous tone usually observed for smooth flat ice which has formed under quiescent conditions. The level of the tone varies with the development of the ice. Inhomogeneous tone is observed in continuously opening leads as new ice forms and ages.

2.2 Texture

Interpretation: The texture refers to the spatial variation of the pixel tone or brightness. Whereas tone is measured for a single element, texture is a spatial quality comprised of many pixels of varying tone. Fine texture refers to minor variation of tone over a scale of a few pixels. These could be variation of the tone over a scale of a number of pixels. Course texture has the appearance that it could be rough to the touch.

Significance: An important parameter for ice interpretation.
Consistent flat ice will have very little if any texture.
Second year ice comprised of trash ice will have a very rough inconsistent texture.

Cause: Due to the spatial variation in the electromagnetic properties and physical character of the ice surface in conjunction with the spatial resolution of the radar. Again this quality is dependent on the scale over which the evaluation is performed. Electromagnetic properties would include variations in the ice types and physical characteristics could be protrusions in the ice surface which give enhanced radar returns.

2.2.1 Mottled Texture

Interpretation: Texture with a speckled characteristic.

Significance: Texture commonly observed for multi-year ice. Especially noticeable for consolidated landfast multi-year ice.

Cause: The Melt Ponds commonly observed in conjunction with the drainage channels form the mottled texture.

2.2.2 Homogeneous Texture

Interpretation: Homogeneous texture is consistent uniform texture within an area of measurement. The texture can vary from coarse to fine. Inhomogeneous texture is a variation in the texture with the same area of measurement.

Cause: Homogeneous texture usually observed with a floe and for larger areas where ice developed at a uniform rate. Inhomogeneous texture usually observed for ice that forms at different times, rates, and under varying circumstances.

2.3 Contrast

Interpretation: Contrast is the variation of the tone in an image. High contrast indicates a wide spread between the darkest pixel tone and the lightest pixel tone. For low contrast images the spread between darkest and brightest tones is diminished.

Cause: Flat young ice with newly formed ridges will usually have high contrast. Ridges produce bright return whereas flat young ice produces dark return. Multi-year ice usually has low contrast since the brightness of the ridges has diminished due to weathering and the background has brighten due to changes in the crystal structure of the ice.

Note: The contrast is limited by both the presentation media and ability of the interpreter to distinguish tonal variations. Typical media such as film are limited to approximately 16 tonal levels, which is 4-bit data. Digital data produced by the CIRS and STAR-1 are 8-bit data which generates 256 tonal levels. As a result the ability of the interpreter to observe the data depends on how the digital data are mapped to the display media.

2.4 Geometry

Refers to the shape of an object. Probably more appropriate under features.

2.5 Matrix

Features are identified as a result of tonal variation from a background or dominant tone. Such tonal variations are generated by lines or edges. The Matrix member refers to the tone or characteristics of the background. The background has no primary shape or distinguishing characteristics.

The matrix can be defined to have a texture.

2.5.1 Bright on Dark

Interpretation: The bright tone refers to the feature.

Significance: It is assumed that the bright tone feature originated from the parent ice. As a result the bright tone is usually attributed to increased roughness caused by physical deformation.

2.5.2 Dark on Bright

Interpretation: The dark tone refers to the feature.

Significance: Commonly associated with fractures which contain open water or first-year ice which has frozen under calm conditions.

Also observed for first year ice floes which have fractured, diverged and frozen into a matrix of new ice. The new ice has a bright tone in the early stages of development due to salt deposition on the surface. As the salt leaches back into the surface the tone brightness diminishes. This tonal variation occurs over a period of less than 7 days.

3. FEATURES

Refers to items which have some physical and image attributes.

3.1 Ridge

Interpretation: Ridges are bright lines. These lines are usually continuous, but intermittent breaks are common. Ridges appear as bright tone against the darker background of parent ice. The dark background is usually flat undeformed ice.

The thickness of the line indicates the size of the ridge. Wider lines indicate higher and wider ridges. The width and the height of the ridge indicates the nature of the parent ice. The maximum ridge height is no more than 15 times the thickness of the parent ice. Furthermore, the width of the ridge is related to the height of the ridge.

The ridges lengths can be in the order of hundreds of metres or kilometres long. The longer ridges are observed for thicker, and thus stronger ice types.

Definition: A ridge is a linear pile of fractured/rubbled ice blocks.

Cause: Compressive internal ice stress results in convergence which causes ice sheet to buckle both upward and downward. A plastic failure mode is assumed since any deformation remains after the stress is released.

Context: Most commonly observed at the interface of ice floes. Pressure ridges can also form in flat undeformed ice. A Limiting Stress Theory applies which states that the ice will fail at the weakest point or area.

The density and the size of ridges increases near coastal areas where internal ice stresses are maximized as the ice moves toward the coastline.

3.1.2 Rafting

Interpretation: Rafting appears as a bright linear lines against a grey tone background characteristic of young ice.

Significance: Rafting is characteristic of younger thin ice types. The ice thickness is typically less than 30 centimetres. The direction of the compressive forces can be determined by the pattern of the rafting.

Definition: Rafting is a specialized form of ridging where the ice sheet does not buckle at the point of failure.

Cause: Rafting is the overthrusting of one ice sheet by another. The ice can be overthrust for distances in the scale of tens of metres. There is a predominance of thrusting in one direction. Usually observed for younger thin ice types. Rafting indicates compressive forces in the ice.

3.1.2.1 Finger Rafting

Interpretation: Rafting appears as a bright linear feature against the smooth dark tone background. There is a sine wave geometry on the scale of hundreds of metres.

Cause: Is the overthrusting of one ice sheet by another. Occurs in young thin ice. The overtrusting alternates between sheets to create an interlocking finger appearance. Usually observed for younger thin ice types. Rafting indicates compressive forces in the ice.

3.1.3 Shear Ridge

Interpretation: They are bright linear continuous lines against a dark background. Very similar in appearance to normal pressure ridges, except that they are straight in nature over scales of kilometres.

Definition: A ridge created by the shear action of two ice sheets as opposed to pure compressive forces.

Significance: Characteristic of first-year ice conditions.

Cause: Produced by shearing action of two ice sheets as a result of internal ice stress. One of the ice sheets is usually fixed. For example if one sheet is landfast.

Context: Observed near coastal area and channels. Not observed until very close pack ice or consolidated ice conditions are achieved.

3.1.4 Weathered Ridges

Interpretation: Weathered ridges appear as bright linear features against a darker tone background. The tone of weathered ridges is diminished from that of new ridges.

Significance: Weathered ridges indicate that the parent ice has aged. This does not however prevent new ridges from being formed.

Cause: Weathered defines the age of ice ridges. The bright return of a ridge is caused by the physical dimensions of the fractured ice floes (which act as corner reflectors). New ridges have sharp edged blocks which give relatively good radar returns. In many instances the parent ice is flat and smooth which produces a dark tone. As a result the bright new ridges are very prominent against a dark background. As the ridges are exposed to environmental conditions the sharp edges are weathered causing smoother rounded edges on ice blocks which produce less radar return intensity. Furthermore, the surrounding parent ice is usually subjected to weathering and dynamic forces which damage the flat surface and cause a general increase in the background final quality.

Context: Characteristic of Second-year and Multi-year ice. Common in the Beaufort Sea, Arctic islands and Eastern Arctic. Not likely to be observed in such areas as the Gulf of St. Lawrence.

3.2 Crack

3.3 Fracture

Interpretation: A fracture appears as a dark tone, linear feature with sharp distinct edges. The edges exhibit a very marked change in tone.

Definition: A fracture is a crack in the ice which has opened to expose open water.

Significance: The fractures usually contain open water as a result of recent motion. However, if quiescent conditions occurred immediately after the fracture was formed the fracture could contain flat first year ice of considerable thickness.

Fractures are most common to first year or younger ice.

Fractures are sharpest and straightest for thicker forms of ice. For thinner forms of ice small pieces usually spawn at the edges.

Cause: The opening is caused by a tensile diverging action or a shearing action. Fractures containing open water indicate that the ice has very recently experienced motion. The nature of the fracture can give an indication of ice thickness and age.

Context: Observed in very close pack ice and/or consolidated ice.

Navigation: Depending on the size some fractures can be suitable for navigation. Fractures indicate divergence which suggests non-compressive ice forces.

3.3.1 Shear Fracture

Interpretation: A dark tone trapezoid shaped area with cracks at opposing ends.

Definition: A fracture which is formed by shearing action.

Significance: Indicates the presence of an internal ice stress. Pure shear is a transformation of pure compressive forces.

Cause: Generated by the shearing action of two ice sheets.

Navigation: Compressive forces can be implied from observed shear. Potential dangerous situation depending on magnitude and ice conditions.

3.4 Lead

Interpretation: Leads are distinguished by their dark tone in a long linear shape and very wide extent. This tone may be brighter but is often very dark. Leads have typically little texture, except for obvious pieces of ice floating in them.

Definition: Leads are by definition areas of open water sufficiently large for vessels to navigate. Thus they are on the order of kilometres wide and tens of kilometres long.

Significance: The presence of leads indicates ice motion, usually pure divergence.

Context: The parent ice is usually very close pack ice and likely consolidated.

Cause: Generated by divergence of ice and not shear action.

3.4.1 Shore Lead

Definition: A specialized type of Lead. The lead is created as the ice moves off the coastline.

3.5 Ice Edge

Interpretation: The ice edge is indicated by a major change in tone.

Definition: The demarcation between a large area of open water and a large area of ice cover. Large areas are defined in terms of hundreds of square kilometres.

Cause: The ice edge marks the balance point between the growth and ablation of ice. There may be advances of the ice edge as growth exceeds the melting or vice versa if growth diminishes.

3.6 Ice Floe

Interpretation: A floe is a clearly identifiable area of uniform tone and texture surrounded by a different tone and texture.

Definition: In open water an ice floe is a contiguous piece of ice surrounded by water. The ice is either one homogeneous sheet or a conglomerate of ice pieces frozen together into one mass.

Significance: Indicates the past history of the ice motion. Very important identification criteria for multi-year ice floes in first-year ice.

Cause: Multi-year ice floes usually show up very bright in the dark background matrix of first-year ice.

3.6.1 Angular Floe

Interpretation: Ice floes which can be observed have sharp angular shapes like polygons. The edges are usually defined by changes in tone and not likely by ridges.

Significance: Angular floes indicate that recent fracturing has occurred.

Definition: An ice floe which has a shape. Edges generally consist of straight lines.

Cause: Angular ice floes are usually observed for first-year ice and younger. Angular ice floes indicate recent motion since sharp edges have not yet experienced sufficient motion to cause wearing of edges.

3.6.2 Rounded Floe

Interpretation: An area comprised of uniform tone and texture which is predominantly circular.

Significance: Common shape for ice floes which have undergone considerable ice motion. During ice motion contact between ice floes causes ablation at the edges. Subsequently sharp edges, characteristic of angular floes are worn off.

Multi-year floes have rounded shapes in most cases.

Young to first year ice can have rounded shapes in low concentration conditions which promote ice floe impacts.

Definition: An ice floe which has a circular to oval shape.

Cause: In a dynamic regime thicker ice floes wear at the edges due to interaction with other floes. As a result sharp protruding edges are worn giving clear circular appearance.

3.7 Melt Pond

Interpretation: Melt ponds appear as circular areas of uniform tonal quality. Ponds are in the order of metres in diameter.

Significance: During the summer season the ice surface melts. Melt water either drains off via a network of drainage channels or ponds in low lying areas. These low lying areas are defined as melt ponds. Melt ponds do not penetrate the bottom of an ice floe.

Cause: Are created on the surface of floes as a result of a thaw. Resultant water unable to drain off surfaces collects in ponds. Most often observed on multi-yr ice floes.

3.8 Distinct Feature

Interpretation:

Cause: Features appearing distinct indicate age, formation process, interaction, dynamics. Featureless ice is usually very old or very young.

4. PATTERNS

Refers to a combination of features in a specific arrangement. Patterns are observed on both the image and ice regime.

4.1 Concentration

Interpretation: When determining total ice concentration all dark tone is interpreted as open water. All other non-dark tone is interpreted as ice cover. Over a fixed area the total ice cover is integrated and expressed as a portion of the area.

The area is a quantity which is selected in a subjective fashion. For instance if a single ice floe were observed to be 5 kilometres in diameter it would not be reasonable to evaluate the concentration over an area smaller than 25 square kilometres.

Definition: The total quantity of an area covered by ice. All ice types are considered in calculating the total quantity. The coverage is expressed as tenths.

Significance:

Cause: Concentration of 10/10 indicates complete ice coverage and 0/10 indicates open water. Total 10/10 concentration commonly observed under winter ice conditions and zero concentration under summer ice conditions.

Navigation: High ice concentration, especially of old ice, is an impediment for vessel navigation. Some combinations of concentration and ice type actually prevent vessel navigation.

4.2 Ridge Pattern

Interpretation: Bright ridge features against the dark background of smooth ice creates a pattern over scales of tens of kilometres.

Cause: Ridge pattern indicates compressive forces over a large area. A lack of ridges, especially for smooth flat ice, indicates an absence of compressive forces.

4.2.1 Lacy Ridge Pattern

Interpretation: Bright ridge features against the dark background of smooth ice creates a pattern over scales of tens of kilometres.

Cause: Most commonly observed in young ice. The dark smooth background usually exhibits a "transparent appearance".

4.2.2 Parallel Ridge Pattern

Interpretation: Generated by straight ridges oriented parallel to each other.

Significance: Characteristic relationship between shear ridges.

Cause: Created by successive start and stop actions of two ice sheets which always move in the same direction relative to each other.

Navigation: Generally because of the density and size of the ridges they are difficult to traverse by a vessel.

4.2.3 Polygon Ridge Pattern

Interpretation: Generated by straight ridges oriented a angles to each other. Observed over scales of

4.3 Ice Edge Rubble

Interpretation: An area of very bright fine texture. The shape of this feature is always long, in the direction of the ice edge.

Cause: Found only at the edge of the ice. The ice edge forms the demarcation between an area of open water and sea ice of any form, whether fast of drifting. The ice edge is in the order of tens of kilometres in length and the area is in the hundreds of square kilometres in area.

4.4 Fracture Pattern

4.4.1 Parallel Fracture Pattern

4.4.2 Polygon Pattern Fractures

5. CLASSIFICATIONS

6. PROCESSES

A condition which is inferred form other information observed on a SAR image.

6.1 Dynamic

Refers to ice which is in motion. The motion could be a transformation, rotation or deformation. Ice motion is usually a combination of all three types of motion.

6.1.1 Divergence

Interpretation: Observed as fractures which are increasing in width. Observed as ice concentration which is decreasing only because of advection.

For active recent divergence some open water will be observed. The open water is observed as very dark tone.

In many cases there is a variation in the dark tone across a diverging area as new ice forms.

Definition: Two points which separate by pure transformation are defined as diverging. For ice the definition applies to two lines which are separating by pure transformation. Divergence only continues as long as the separation occurs. Once motion stops the ice is not diverging.

Divergence is a relative measurement. A large ice sheet can be in motion with no divergence (or convergence or rotation) observed.

Significance: Can occur for any type of ice. However, a fracture usually occurs at the weakest point.

Consolidated ice diverges from fractures.

Unconsolidated ice (i.e. very close pack ice) diverges by decreasing concentration.

Context:

Cause: Open water, fractures and leads are generated by diverging motion.

6.1.2 Convergence

Definition: Two points which close (i.e. come together) by pure transformation are defined as converging. For ice the definition applies to two lines which are coming together by pure transformation. Convergence only continues as long as the separation distance decreases. Once motion stops the ice is not converging.

Convergence is a relative measurement. A large ice sheet can be in motion with no convergence (or divergence or rotation) observed.

6.3 Active Freezing

Interpretation: Identified by bright tone in the lead.

Cause: Indicates the age of the lead, and the weather in the past 12-24 hrs. There may be gradations in the tone as a result of the variation in the stage of development as the fracture or lead forms.

6.4 Formed in a Lead

Interpretation: Ice formed in a lead can have a rough surface due to winds blowing.

Cause: This often relates to a lead opening caused by strong winds interacting with the ice surface.

6.5 Consolidated

Interpretation:

Cause: Refers to ice that has been frozen or refrozen to form a coherent ice formation.

7. OTHER

Constructs form the Session II PCS experiment which cannot be included in any of the preceding categories are listed in this section.

7.1 Smooth Surface-Rough Surface

Interpretation: A rough surface has a wide variation in the tone over an area and has a significant variation in the tonal quality between adjacent pixels. A smooth surface has a narrow variation in the tone over an area. A rough surface appears abrasive to the touch, whereas a smooth surface appears smooth to the touch.

Cause: Rough surfaces are observed for rubbled ice areas where floes have been fractured and piled over an area. Smooth surfaces commonly indicate ice which has frozen under quiescent conditions has not experienced any dynamic motion.

7.2 Much Rubble-No Rubble

Interpretation: A heavily rubbled/ridged area has a very bright coarse texture. Areas are in excess of hundreds of metres in diameter.

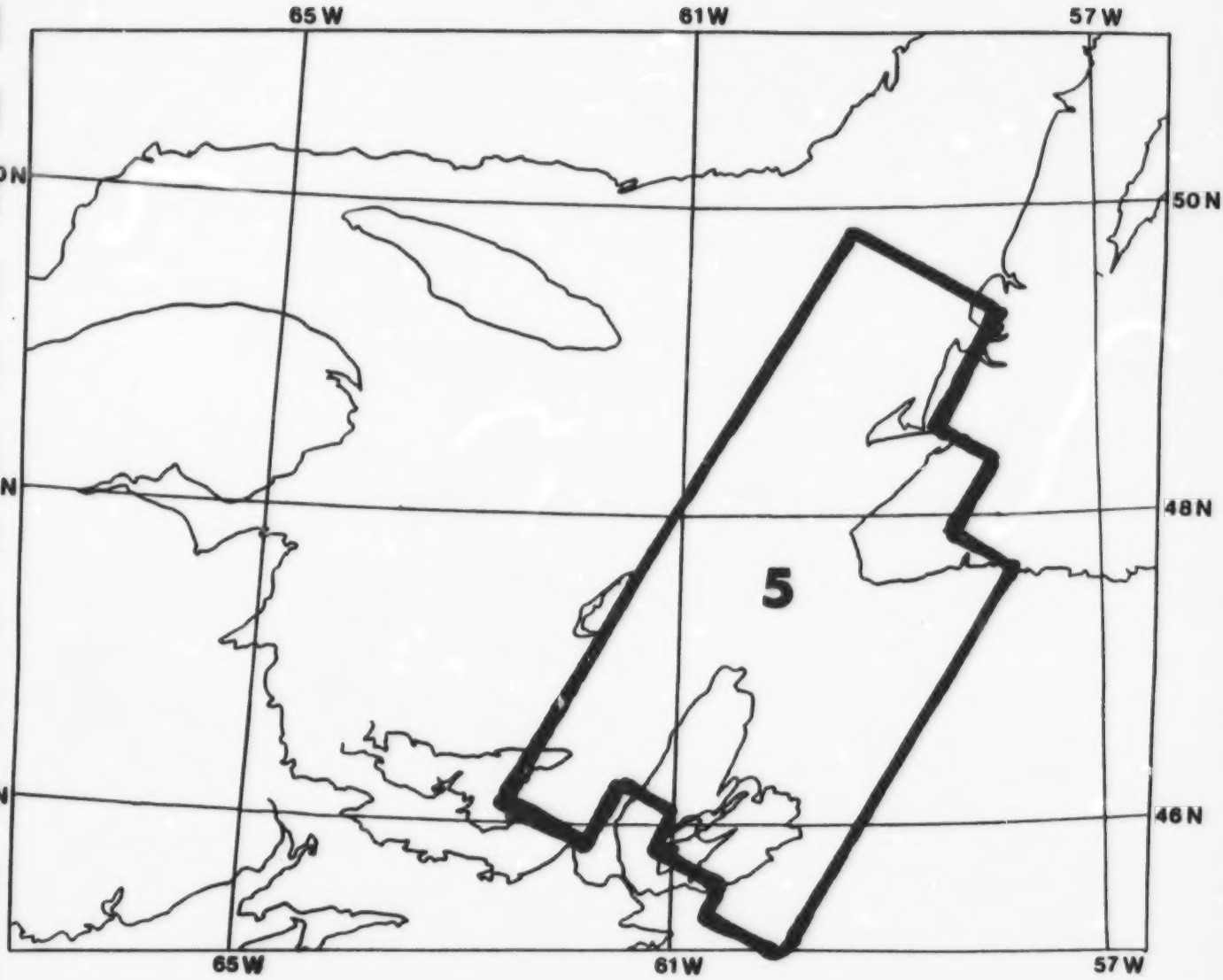
Cause: Rubble is broken ice forced up by compressive ice pressure. Usually observed along coastal areas where high compressive forces are observed.

APPENDIX E

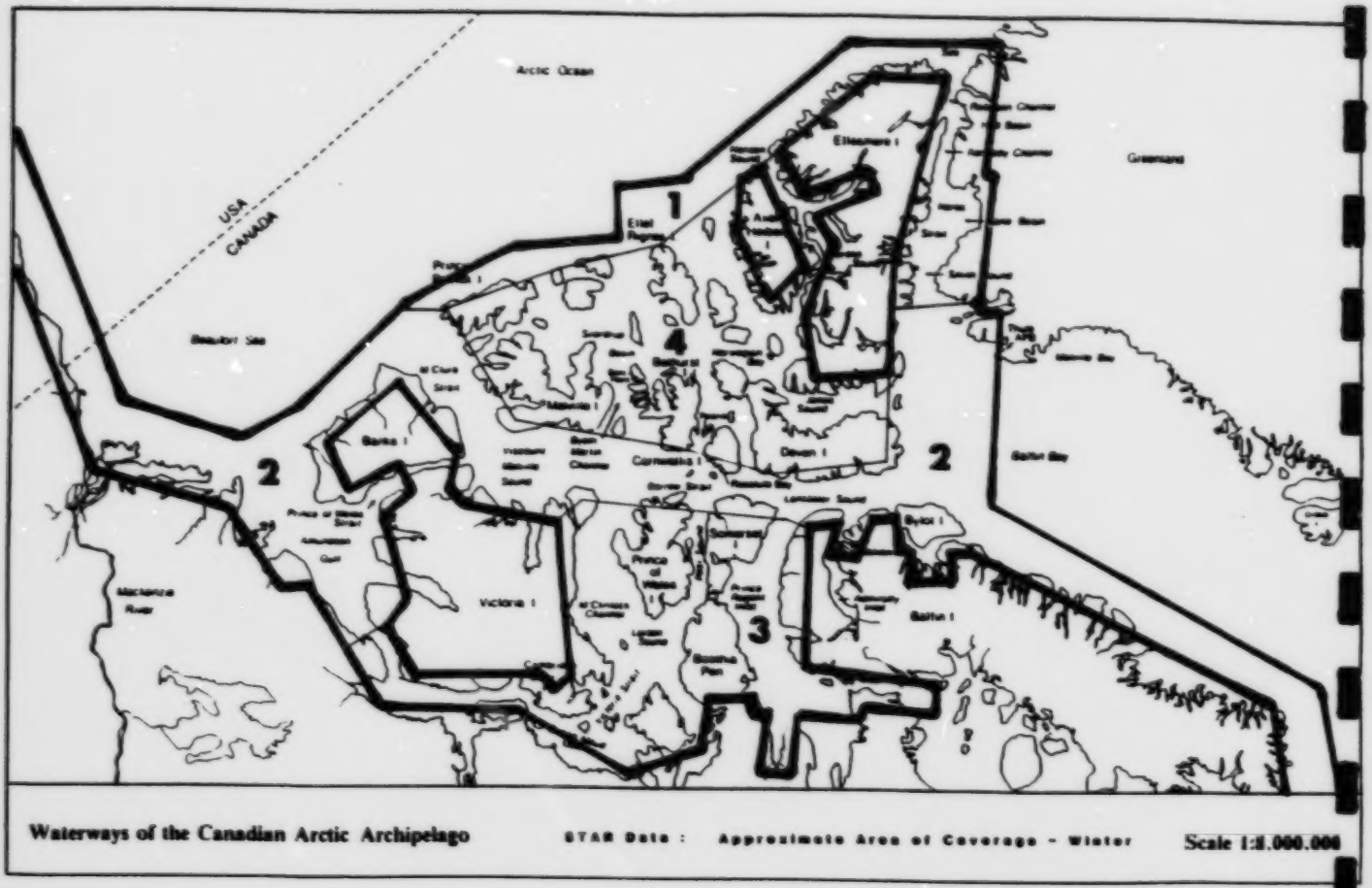
MATRIX OF SAR DATA

ICE DATA

	A	B	C	D
1	GEOGRAPHIC LOCATION	STAR-1 Data	STAR-2 Data	STAR-1 Not Trans'd
2	1. Arctic Ocean		winter '88	
3	Nares		part winter '88	winter '88
4	Smith Sound	winter '86	winter '87,'88	
5	Kane Basin	winter '86	winter '87,'88	
6	Robeson Channel	winter '86	winter '87,'88	
7	2. Beaufort	winter '89	winter '88	
8	Amundsen		winter '88	
9	Chukchi	winter '89		
10	Baffin - north	winter '86	winter '87,'88	
11	- west	winter '86	winter '87,'88	
12	Davis		winter '88	
13	Lancaster	winter '86	winter '87,'88	winter'87,'88,'89
14	- northern		winter '88	winter '86
15	- eastern	winter '86	winter '87,'88	
16	Barrow	winter '86	winter '87,'88	winter '87,'88
17	Vis. Melv. Sd	winter '86	winter '88	
18	M'Clure	winter '86	winter '88	
19	3. Arctic Is. S. of Lanc.			
20	Pr. of Wales Sd		winter '88	
21	Qu. Maud Gulf	winter '86		? winter '89
22	M'Clintock Ch.	winter '86		? winter '89
23	Victoria St.			winter '88
24	Larsen Sound	winter '86		? winter '89
25	Peel Sound	winter '86		? winter '89
26	Pr. Regent In.		winter '88	
27	4. Arctic Is. N. of Lanc			
28	Sverdrup Basin	winter '86	winter '88	
29	Bent Horn		winter '88	winter '89
30	Byam Martin Ch.	winter '86	winter '88	
31	Norwegian Bay	winter '86	winter '88	
32	Hell Gate	winter '86	winter '88	
33	Eureka Sound	winter '86	winter '88	
34	Nansen Sound	winter '86	winter '88	
35	5. Gulf of St. Lawrence		winter '87	
36	Other East Coast			
37	6. Hudson Bay			



Gulf of St. Lawrence STAR Data : Approximate Area of Coverage



Waterways of the Canadian Arctic Archipelago STAR Data : Approximate Area of Coverage - Winter Scale 1:8,000,000

APPENDIX F

NEXPERT OBJECT TECHNICAL NOTES

Knowledge Design

Key words: observer - resource allocation - problem - knowledge - domain expert - focus of attention - hybrid tool - objects and rule representation - intelligent interface - incremental compilation - interactivity

What is a problem?

The notion of *problem* is at the essence of an intelligent system. In this context, a problem may be defined as an event requiring a more or less immediate allocation of intellectual resources from the *observer* of that event. If one is to analyze the nature of a problem, one has to consider the observer in the description.

Thus, there are two major components in problem-solving: *(i)* the elementary chunks of knowledge and their links, and *(ii)* the behavior relevant to the processing of these chunks (for experts, such behavior includes rules of thumb, experiential learning and intuition).

NEXPERT *OBJECT* is a *hybrid system tool* which combines these components to create representation and reasoning mechanisms. It is based on the principle of *knowledge design*, rather than that of *knowledge engineering*. The latter term implies the engineering of a problem in an Ai language, which is often limited in performance by a poor human-computer interface and requires a high-priced knowledge engineer. NEXPERT *OBJECT* grew out of an effort to demystify and deploy a powerful new technology, beyond classical knowledge engineering. Some key issues are described in the following pages.

Designing knowledge

The concept of knowledge design is based on the ability of domain experts to be fully involved in the construction of a knowledge base, manipulating many high-level tools to help model a task.

NEXPERT *OBJECT* represents such "high-level" programming. It allows computation of chunks of knowledge and representation of mental models. This gives the actual preservers of knowledge (the domain experts) direct access to the intelligent agent. With NEXPERT, problem-solving becomes a desktop functionality, linking the human and artificial intelligences into an overall more resourceful entity.

In order to allow this linking, the intelligent system must have a powerful *interface*, based on the "WYSIWYG & WYDIWYS" principle (What You See Is What You Get & What You Do Is What You See)

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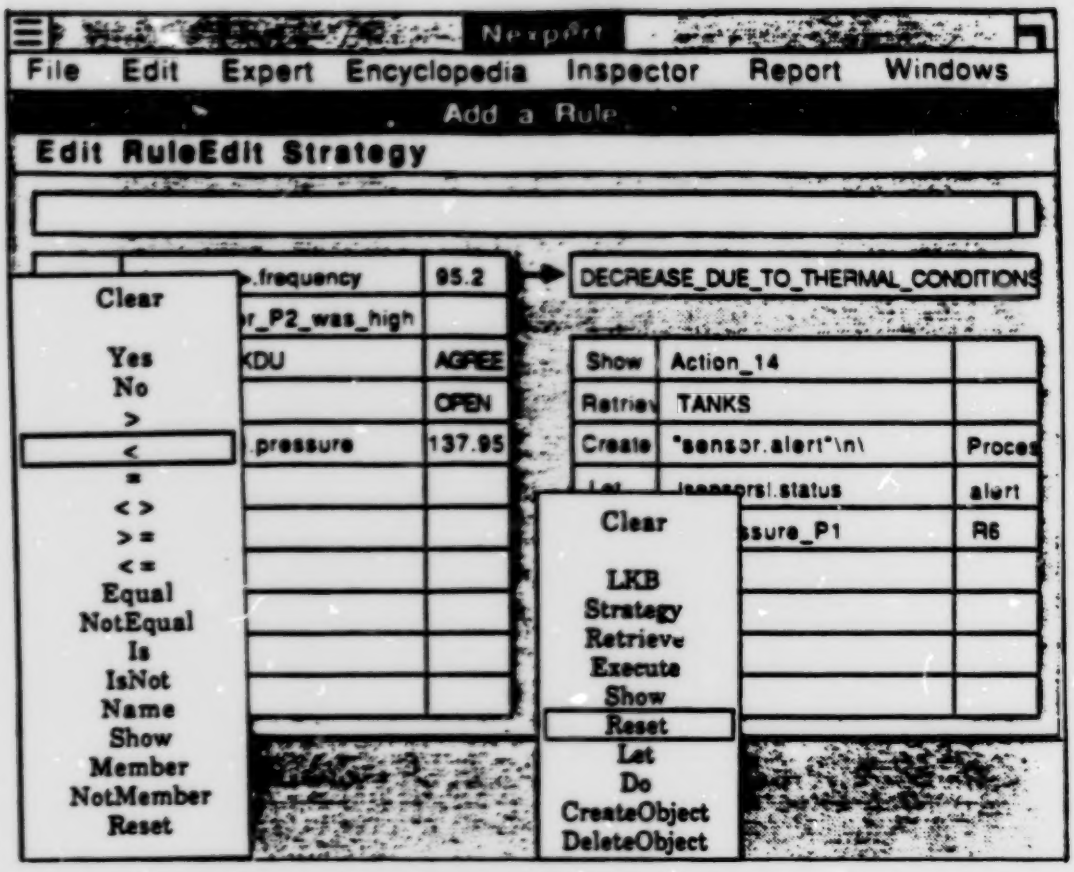
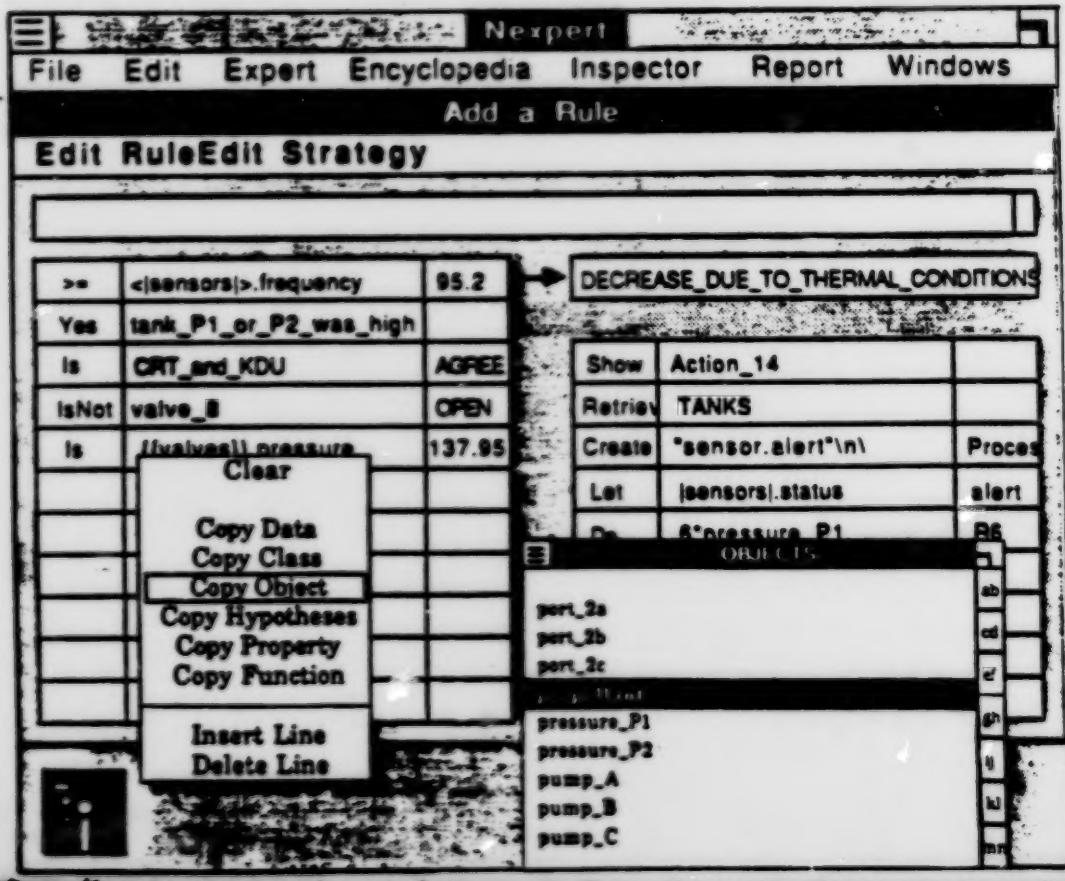

Nexpert
File Edit Expert Encyclopedia Inspector Report Windows
Add a Rule
Edit RuleEdit Strategy
.frequency
95.2
DECREASE_DUE_TO_THERMAL_CONDITIONS
r_P2_was_high
KDU
AGREE
OPEN
pressure
137.95
Show
Action_14
Retriev
TANKS
Create
"sensor.alert"\n\
Proces
alert
R6
Clear
Yes
No
>
<
=
< >
>=
<=
Equal
NotEqual
Is
IsNot
Name
Show
Member
NotMember
Reset
Clear
LKB
Strategy
Retrieve
Execute
Show
Reset
Let
Do
CreateObject
DeleteObject


Nexpert
File Edit Expert Encyclopedia Inspector Report Windows
Add a Rule
Edit RuleEdit Strategy
>=
<|sensors|>.frequency
95.2
DECREASE_DUE_TO_THERMAL_CONDITIONS
Yes
tank_P1_or_P2_was_high
Is
CRT_and_KDU
AGREE
IsNot
valve_8
OPEN
Is
137.95
Show
Action_14
Retriev
TANKS
Create
"sensor.alert"\n\
Proces
Let
|sensors|.status
alert
R6
Clear
Copy Data
Copy Class
Copy Object
Copy Hypotheses
Copy Property
Copy Function
Insert Line
Delete Line
OBJECTS
port_2a
port_2b
port_2c
pressure_P1
pressure_P2
pump_A
pump_B
pump_C

Top-down & bottom-up editing of knowledge

It is difficult to predict the approach a knowledge designer will take while constructing a particular knowledge base. One designer may begin by describing instances, for example, while another will choose to begin with classes and sub-classes, or with rules. In order to address this design issue, NEXPERT *OBJECT* is built with a multi-directional knowledge editor, allowing complete flexibility.

Top-down editing means that one can edit objects from the top level down to the bottom, first describing top-level classes, then subclasses, then objects or instances, and so on.

Bottom-up editing is the ability to define objects with their full or limited set of properties *before* editing (perhaps before knowing their class or full description). If the class is not yet well specified, it does not need to be created before using the member objects. This provides a fundamental degree of freedom to the knowledge designer.

Incrementally compiling objects from the rules

A domain expert may choose to start directly from the rules, immediately using different objects and classes, and their properties. When compiling those rules, the object structures are *automatically generated* with their respective properties. They can be found in the respective graphic editors.

Incremental compilation of knowledge in a multi-directional fashion is critical for the creation, editing, verification and maintenance of the knowledge base.

Inheritance

The hierarchical relations between objects allow one to *pass properties and their values* from one object (parent) to another (child). Hence, a considerable economy of representation and declaration is made.

An object can inherit the value of any of its properties from a parent object. Moreover, NEXPERT *OBJECT* supports *multiple inheritance*, which means that an object can have two or more parents.

Objects can also benefit from *class inheritance*. NEXPERT *OBJECT* supports *user defined inheritance strategies*, in order to customize the way any given property of an object should inherit values from higher structures, be they direct parents or classes. Such strategies are declared in a meta-slot. They also direct what property is inheritable. Methods attached to the meta-slots of the object and class

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properties can also be inherited. This inheritancy is not only a mechanism for economy, but accounts for the overall reasoning power. Through their meta-slots, objects can alter the inference process.

Inheritance is performed *dynamically* during runtime, or it can be pre-processed. Thus, NEXPERT *OBJECT* does not have *only* a pre-processor of the property values, which would limit the use of inheritance. Property values are determined during the runtime, allowing dynamic access to all inheritable values.

Dynamic objects

In NEXPERT *OBJECT*, objects and their links to other objects or classes can be created or modified by rules and/or by object meta-slots when they apply. Dynamic objects belong to classes and therefore can inherit properties and their values. Furthermore, rules can address these objects via their pattern-matching functionalities (see next section).

For example, states of inference for a given set of variables can be stored as object structures or hierarchies, allowing the pursual of *hypothetical reasoning*.

The *CreateObject* function is also the basis of the transformation of database query results into NEXPERT *OBJECT* data structures on which the system can reason.

Other applications of the dynamic creation of Objects and object links include *simulation* and *temporal processes*.

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Rules and Patterns

Key words: rules - augmented rule format - forward / backward symmetry - declarative access to control mechanisms - pattern matching - lists of objects - lists of subobjects - class level inference

Rules

NEXPERT *OBJECT* is a *hybrid* system, combining structured representations and rules. The rules are the elementary chunks of knowledge processed by NEXPERT *OBJECT*. A rule is a mode of representation of dynamic chunks of knowledge, linking facts or observations to assertions or actions. The basic structure of the NEXPERT rules is of the type:

if...then do...

Rules in the NEXPERT technology have a unique format called "Augmented Rule Format", with such properties as *forward / backward symmetry, rule access to the inference mechanisms,* and *procedural attachments.*

Any rule can be processed either forward or backward, according to the structure of the knowledge base or the presentation of the problem. This important and unique format allows *full integration* of the inference mechanisms.

Rules reason upon facts in order to draw conclusions or make assumptions. The power of rule-based systems lies not only in the inference mechanism but also in the richness of the facts that can be represented.

The complexity of the facts is dependent in turn upon the representation of knowledge adopted for a given system. NEXPERT *OBJECT* is based on Objects similar to frames, schema or schemata, which are high level structures to describe complex elements of knowledge and their structural organization, apparent, real or reputed. With such structures it is possible to represent deep (versus flat) worlds with hierarchical or multi-level descriptions. This structure leads to the notion of patterns.

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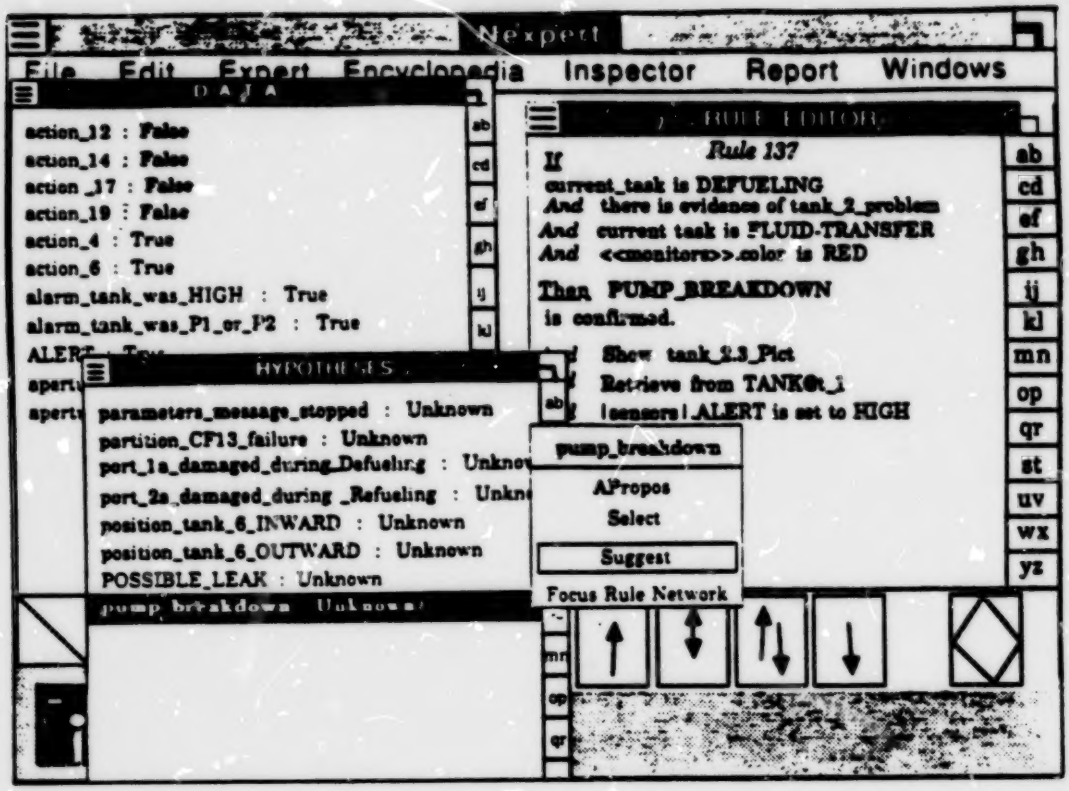
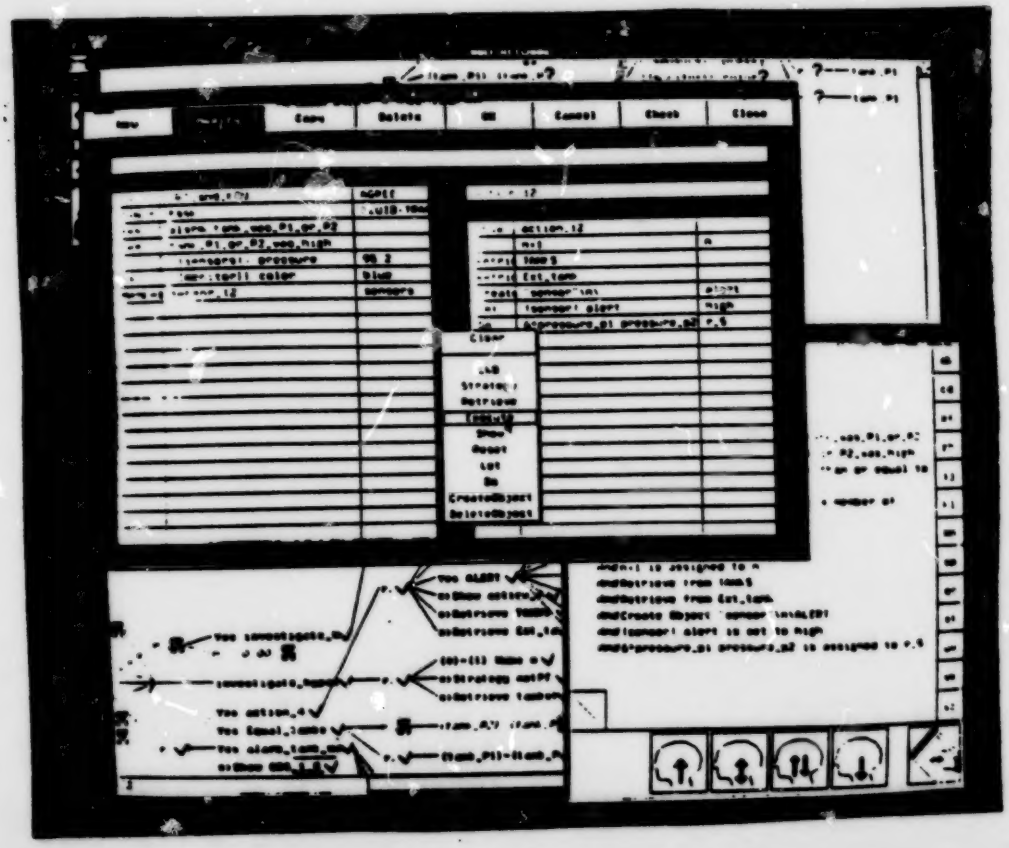

Nexpert
File Edit Expert Encyclopedia Inspector Report Windows
DATA
action_12 : False
action_14 : False
action_17 : False
action_19 : False
action_4 : True
action_6 : True
alarm_tank_was_HIGH : True
alarm_tank_was_P1_or_P2 : True
HYPOTHESES
parameters_message_stopped : Unknown
partition_CF13_failure : Unknown
port_1a_damaged_during_Defueling : Unknow
port_2a_damaged_during_Refueling : Unkn
position_tank_6_INWARD : Unknown
position_tank_6_OUTWARD : Unknown
POSSIBLE_LEAK : Unknown
pump_breakdown Unknown
RULE EDITOR
Rule 137
If
current_task is DEFUELING
And there is evidence of tank_2_problem
And current task is FLUID-TRANSFER
And <<monitored>>.color is RED
Then PUMP_BREAKDOWN
is confirmed.
Show tank_2.3_Pict
Retrieve from TANK@t_1
|sensors|.ALERT is set to HIGH
pump_breakdown
APropos
Select
Suggest
Focus Rule Network



Moreover, forward chaining can be controlled locally via the Strategy menu which allows one, for instance, to disable the forwarding of Right-Hand Side actions (or actions originated elsewhere).

Backward chaining

This mode of reasoning corresponds to a goal-driven behavior for solving problems. The system navigates through the knowledge base, discovering the rules and subgoals relevant to the user's and/or the system's goal(s). (NEXPERT can handle multiple goal processing and automatically generates relevant goals).

Strategies allow one to modulate the thoroughness of the search in a given subspace of the knowledge base, as well as the local and global directions of the search.

Automatic goal generation

Consider a simple situation: a patient goes to a physician (or a novice aircraft mechanic seeks the help of an expert, etc.) and wonders whether s/he has the flu (a goal infered from a few known symptoms). If the physician can perform only backward chaining thinking from a stated hypothesis, the answer may be NO (not to mention the intractable .86 type of answer). The patient would then walk away with this answer, *and perhaps a much more serious disease* (or a structural problem in the airplane, etc.).

The issue we are emphasizing is the need, obvious from a cognitive standpoint, to automatically *generate alternative goals* when evaluating a problem (in either forward and/or backward chaining). NEXPERT *OBJECT* supports an *automatic goal generation mechanism* which *does not* require specific programming or declaration.

Goals are automatically generated as the factual knowledge is matched to the problem. NEXPERT ensures the coherence of the resulting focus of attention, and allows one to control the consequent evaluation of those alternative goals.

Contextual links

The process of knowledge design involves the "*decompilation*" of human knowledge in order to write the chunks which will compose the knowledge bases in a given representation.

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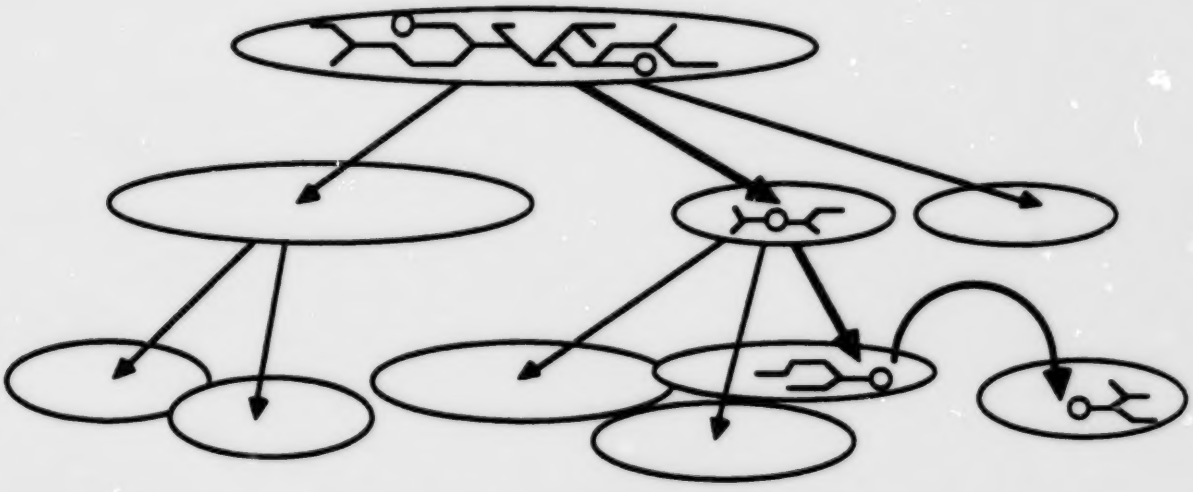
non-monotonically. The backward chaining evaluation of a goal is in turn affected by the Strategy menu which controls the exhaustivity of the process.

The Context mechanism is controlled as well by the Strategy menu, and is accessible from the Right-Hand Side. The exploration of new knowledge islands can be made conditional to the result of the present search.

Finally, inheritance mechanisms are made declarative in NEXPERT *OBJECT*, allowing the user to define the structure of the knowledge at a low level of description.

This approach leads to the concept of *control and maintenance* of a coherent and efficient focus of attention in the presence of many goals and much data to process.



Managing the focus of attention

The diagram above is an example of a horizontal architecture. The context mechanism can be used for progressive refinement of a task as the reasoning process moves into more specific areas. In this example, the top island determines which path is followed. As this path is investigated, the new path is defined by the corresponding contexts. This heuristic method yields an economy in the number of rules and constrains the search space at each step of the process, thereby optimizing the search.

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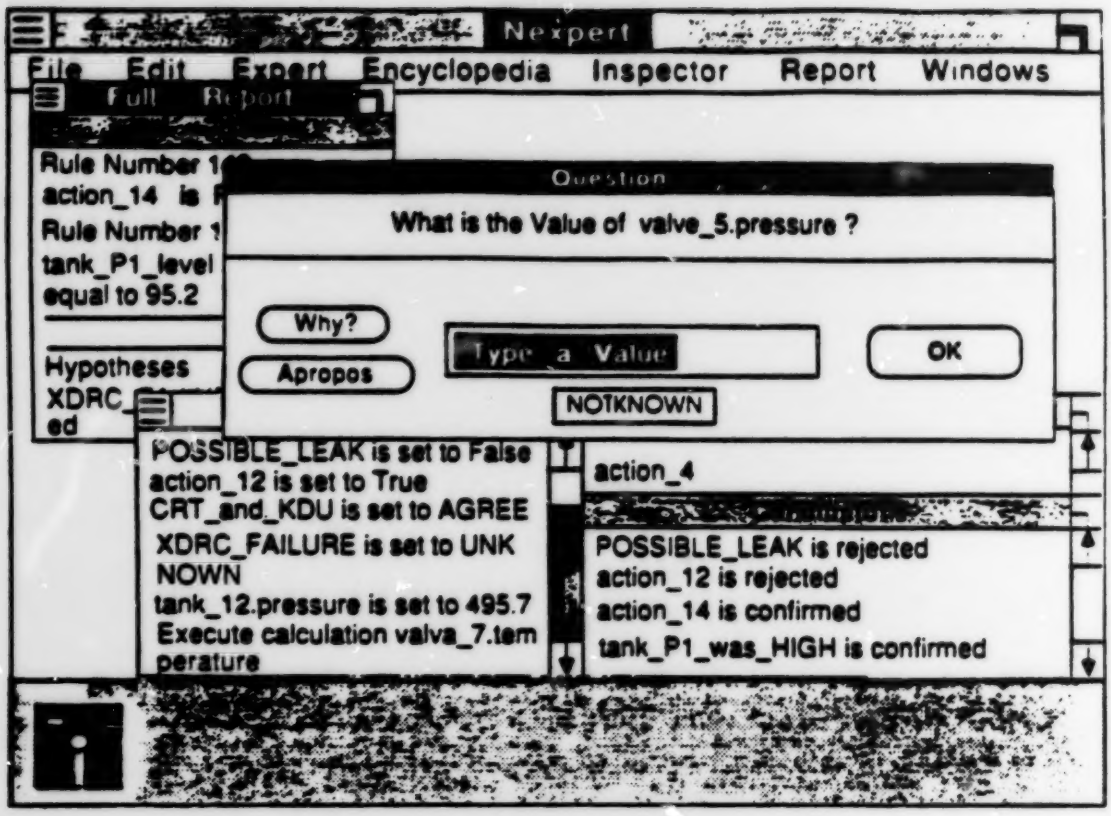
Nexpert
File Edit Expert Encyclopedia Inspector Report Windows
Full Report
Question
What is the Value of valve_5.pressure ?
Why?
Apropos
Type a Value
OK
NOTKNOWN
Hypotheses
XDRC
ed
POSSIBLE_LEAK is set to False
action_12 is set to True
CRT_and_KDU is set to AGREE
XDRC_FAILURE is set to UNK
NOWN
tank_12.pressure is set to 495.7
Execute calculation valva_7.tem
perature
action_4
POSSIBLE_LEAK is rejected
action_12 is rejected
action_14 is confirmed
tank_P1_was_HIGH is confirmed